CHAPTER 6

LUBRICATION AND COOLING SYSTEMS

PRINCIPLES OF ENGINE LUBRICATION

The primary purpose of a lubricant is to reduce friction between moving parts. Because liquid lubricants (oils) can be circulated readily, they are used universally in aircraft engines.

In theory, fluid lubrication is based on the actual separation of the surfaces so that no metal-to-metal contact occurs. As long as the oil film remains unbroken, metallic friction is replaced by the internal fluid friction of the lubricant. Under ideal conditions, friction and wear are held to a minimum.

In addition to reducing friction, the oil film acts as a cushion between metal parts. This cushioning effect is particularly important for such parts as reciprocating engine crankshaft and connecting rods, which are subject to shock-loading. As oil circulates through the engine, it absorbs heat from the parts. Pistons and cylinder walls in reciprocating engines are especially dependent on the oil for cooling. The oil also aids in forming a seal between the piston and the cylinder wall to prevent leakage of the gases from the combustion chamber. Oils also reduce abrasive wear by picking up foreign particles and carrying them to a filter, where they are removed.

REQUIREMENTS AND CHARACTERISTICS OF RECIPROCATING ENGINE LUBRICANTS

While there are several important properties which a satisfactory reciprocating engine oil must possess, its viscosity is most important in engine operation. The resistance of an oil to flow is known as its viscosity. An oil which flows slowly is viscous or has a high viscosity. If it flows freely, it has a low viscosity. Unfortunately, the viscosity of oil is affected by temperature. It is not uncommon for some grades of oil to become practically solid in cold weather. This increases drag and makes circulation almost impossible. Other oils may become so thin at high temperature that the oil film is broken, resulting in rapid wear of the moving parts. The oil selected for aircraft engine lubrication must be light enough to circulate freely, yet heavy enough to provide the proper oil film at engine operating temperatures. Since lubricants vary in properties and since no one oil is satisfactory for all engines and all operating conditions, it is extremely important that only the recommended grade be used.

Several factors must be considered in determining the proper grade of oil to use in a particular engine. The operating load, rotational speeds, and operating temperatures are the most important. The operating conditions to be met in the various types of engines will determine the grade of the lubricating oil to be used.

The oil used in reciprocating engines has a relatively high viscosity because of:

(1) Large engine operating clearances due to the relatively large size of the moving parts, the different materials used, and the different rates of expansion of the various materials.

(2) High operating temperatures.

(3) High bearing pressures.

The following characteristics of lubricating oils measure their grade and suitability:

(1) Flash point and fire point are determined by laboratory tests that show the temperature at which a liquid will begin to give off ignitable vapors (flash) and the temperature at which there are sufficient vapors to support a flame (fire). These points are established for engine oils to determine that they can withstand the high temperatures encountered in an engine.

(2) Cloud point and pour point also help to indicate suitability. The cloud point of an oil is the temperature at which its wax content, normally held in solution, begins to solidify and separate into tiny crystals, causing the oil to appear cloudy or hazy. The pour point of an oil is the lowest temperature at which it will flow or can be poured.

(3) Specific gravity is a comparison of the weight of the substance to the weight of an equal volume of distilled water at a specified

temperature. As an example, water weighs approximately 8 lbs. to the gallon; an oil with a specific gravity of 0.9 would weigh 7.2 lbs. to the gallon.

Generally, commercial aviation oils are classified numerically, such as 80, 100, 140, etc., which are an approximation of their viscosity as measured by a testing instrument called the Saybolt Universal Viscosimeter. In this instrument a tube holds a specific quantity of the oil to be tested. The oil is brought to an exact temperature by a liquid bath surrounding the tube. The time in seconds required for exactly 60 cubic centimeters of oil to flow through an accurately calibrated orifice is recorded as a measure of the oil's viscosity.

If actual Saybolt values were used to designate the viscosity of oil, there probably would be several hundred grades of oil. To simplify the selection of oils, they often are classified under an SAE (Society of Automotive Engineers) system, which divides all oils into seven groups (SAE 10 to 70) according to viscosity at either 130° or 210° F.

SAE ratings are purely arbitrary and bear no direct relationship to the Saybolt or other ratings. The letter "W" occasionally is included in the SAE number giving a designation such as SAE 20W. This letter "W" indicates that the oil, in addition to meeting the viscosity requirements at the testing temperature specifications, is a satisfactory oil for winter use in cold climates.

Although the SAE scale has eliminated some confusion in the designation of lubricating oils, it must not be assumed that this specification covers all the important viscosity requirements. An SAE number indicates only the viscosity (grade) or relative viscosity; it does not indicate quality or other essential characteristics. It is well known that there are good oils and inferior oils that have the same viscosities at a given temperature and, therefore, are subject to classification in the same grade. The SAE letters on an oil container are not an endorsement or recommendation of the oil by the Society of Automotive Engineers.

Although each grade of oil is rated by an SAE number, depending on its specific use, it may be rated with a commercial aviation grade number or an Army and Navy specification number. The correlation between these grade-numbering systems is shown in figure 6–1.

Commercial Aviation No.	Commercial SAE No.	Army and Navy Specification No.
65	30	1065
80	40	1080
100	50	1100
120	60	1120
140	70	

Figure 6–1. Grade designations for aviation oils.

RECIPROCATING ENGINE LUBRICATION SYSTEMS

Dry-Sump Systems

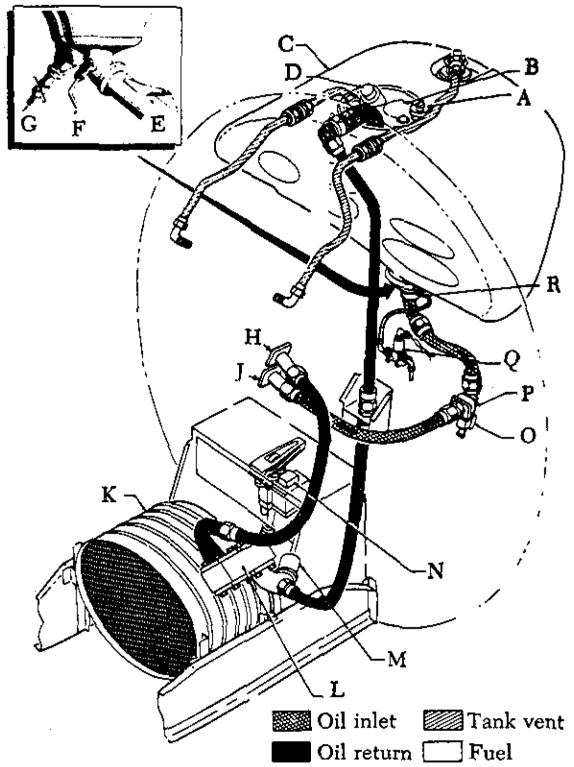
Many reciprocating aircraft engines have pressure dry-sump lubrication systems. The oil supply in this type of system is carried in a tank. A pressure pump circulates the oil through the engine; scavenger pumps then return it to the tank as quickly as it accumulates in the engine sumps. The need for a separate supply tank is apparent when considering the complications that would result if large quantities of oil were carried in the engine crankcase. On multi-engine aircraft, each engine is supplied with oil from its own complete and independent system.

Although the arrangement of the oil systems in different aircraft varies widely and the units of which they are composed differ in construction details, the functions of all such systems are the same. A study of one system will clarify the general operation and maintenance requirements of other systems.

The principal units in a typical reciprocating engine dry-sump oil system include an oil supply tank, an engine oil pump, an oil cooler, an oil control valve, an actuator for an oil-cooler air-exit control, a firewall shutoff valve, the necessary tubing, and quantity, pressure, and temperature indicators. Most of these units are shown in figure 6–2.

Oil Tanks

Oil tanks generally are constructed of aluminum alloy. The oil tank usually is placed close to the engine and high enough above the oil pump inlet to ensure gravity feed. Oil tank capacity varies with the different types of aircraft, but generally it is sufficient to ensure an adequate supply of oil for the total fuel supply. The tank filler neck is positioned to provide sufficient room for oil expansion and for foam to collect. The filler cap or cover is marked with the word "OIL" and the tank capacity. A drain in the filler cap well disposes of any overflow caused by the filling operation. Oil tank vent lines are provided to ensure proper tank



A.	Dipstick screw plug	K.	Oil cooler
B.	Filler neck	L.	Oil control valve
C.	Oil tank	M.	Floating control thermostat
D.	Oil quantity transmitter	N.	Air exit flap actuator
E.	Oil temperature bulb	O.	Oil system drain valve
F.	Fuel connection for oil dilution	P.	Firewall shutoff valve.
G.	Sump drain valve	Q.	Oil dilution valve
H.	Oil outlet from engine	R.	Oil tank sump
J.	Oil inlet to engine		

FIGURE 6–2. Typical lubrication system.

ventilation in all attitudes of flight. These lines usually are connected to the engine crankcase to prevent the loss of oil through the vents. This indirectly vents the tanks to the atmosphere through the crankcase breather.

Some oil tanks have a built-in hopper (figure 6–3), or temperature accelerating well, that extends from the oil return fitting on top of the oil tank to the outlet fitting in the sump in the bottom of the tank. In some systems, the hopper tank is open to the main oil supply at the lower end; other systems have flapper-type valves that separate the main oil supply from the oil in the hopper.

The opening at the bottom of the hopper in one type and the flapper-valve-controlled openings in the other allow oil from the main tank to enter the hopper and replace the oil consumed by the engine. Whenever the hopper tank includes the flapper-

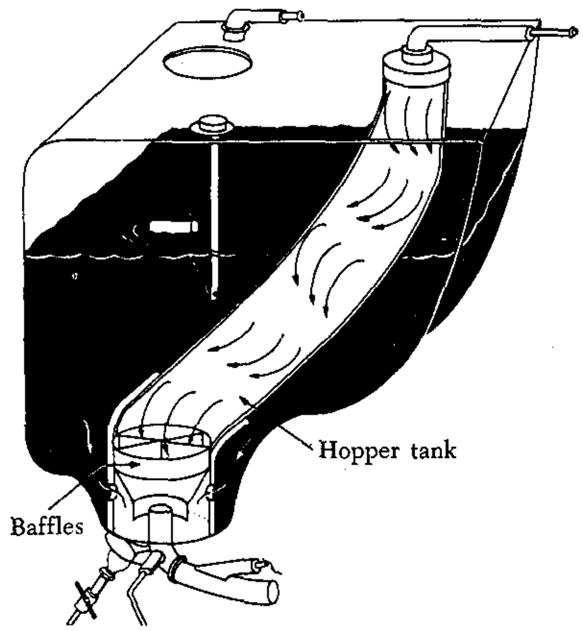


FIGURE 6–3. Oil tank with hopper.

valve-controlled openings, the valves are operated by differential oil pressure.

By separating the circulating oil from the surrounding oil in the tank, less oil is circulated. This hastens the warming of the oil when the engine is started. A hopper tank also makes oil dilution practical because only a relatively small volume of oil will have to be diluted. When it is necessary to dilute the oil, gasoline is added at some point in the inlet oil line to the engine, where it mixes with the circulating oil.

The return line in the top of the tank is positioned to discharge the returned oil against the wall of the hopper in a swirling motion. This method considerably reduces foaming. Baffles in the bottom of the hopper tank break up this swirling action to prevent air from being drawn into the line to the oil pressure pumps. In the case of oil-controlled propellers, the main outlet from the hopper tank may be in the form of a standpipe so that there will always be a reserve supply of oil for propeller feathering in case of engine failure. An oil tank sump, attached to the undersurface of the tank, acts as a trap for moisture and sediment (figure 6–2). The water and sludge can be drained by manually opening the drain valve in the bottom of the sump.

Most aircraft oil systems are equipped with the dipstick-type quantity gage, often called a bayonet gage. Some systems also have an oil-quantity-indicating system that shows the quantity of oil during flight. One type system consists essentially of an arm and float mechanism that rides the level of the oil and actuates an electric transmitter on top of the tank. The transmitter is connected to a cockpit gage, which indicates the quantity of oil in gallons.

Oil Pump

Oil entering the engine is pressurized, filtered, and regulated by units within the engine. They will be discussed, along with the external oil system, to provide a concept of the complete oil system.

As oil enters the engine (figure 6–4), it is pressurized by a gear-type pump. This pump is a positive displacement pump that consists of two meshed gears that revolve inside a housing. The clearance between the teeth and housing is small. The pump inlet is located on the left, and the discharge port is connected to the engine's system pressure line. One gear is attached to a splined drive shaft that extends from the pump housing to an accessory drive shaft on the engine. Seals are used to prevent leakage around the drive shaft. As the lower gear is rotated counterclockwise, the driven (idler) gear turns clockwise.

As oil enters the gear chamber, it is "picked up" by the gear teeth, trapped between them and the sides of the gear chamber, and is carried around the outside of the gears and discharged from the pressure port into the oil screen passage. The pressurized oil flows to the oil filter, where any solid particles suspended in the oil are separated from it, preventing possible damage to moving parts of the engine. Oil under pressure then opens the oil filter check valve mounted in the top of the filter. This valve is closed by a light spring loading of 1 to 3 pounds when the engine is not operating to prevent gravity-fed oil from entering the engine and settling in the lower cylinders of radial engines. If oil were permitted to lie in the lower cylinders, it would gradually seep by the rings of the piston and fill the combustion chamber, contributing to a possible liquid lock.

The bypass valve, located between the pressure side of the oil pump and the oil filter, permits unfiltered oil to bypass the filter and enter the engine when the oil filter is clogged or during a cold engine start. The spring loading on the bypass valve allows the valve to open before the oil pressure collapses the filter, or, in the case of cold, congealed oil, it provides a low-resistance path around the filter. It is felt that dirty oil in an engine is better than no lubrication at all.

Oil Filters

The oil filters used on aircraft engines are usually one of three types: (1) Screen, (2) Cuno, or (3) Air-Maze. A screen-type filter (figure 6–4) with its double-walled construction provides a large filtering area in a compact unit. As oil passes through the

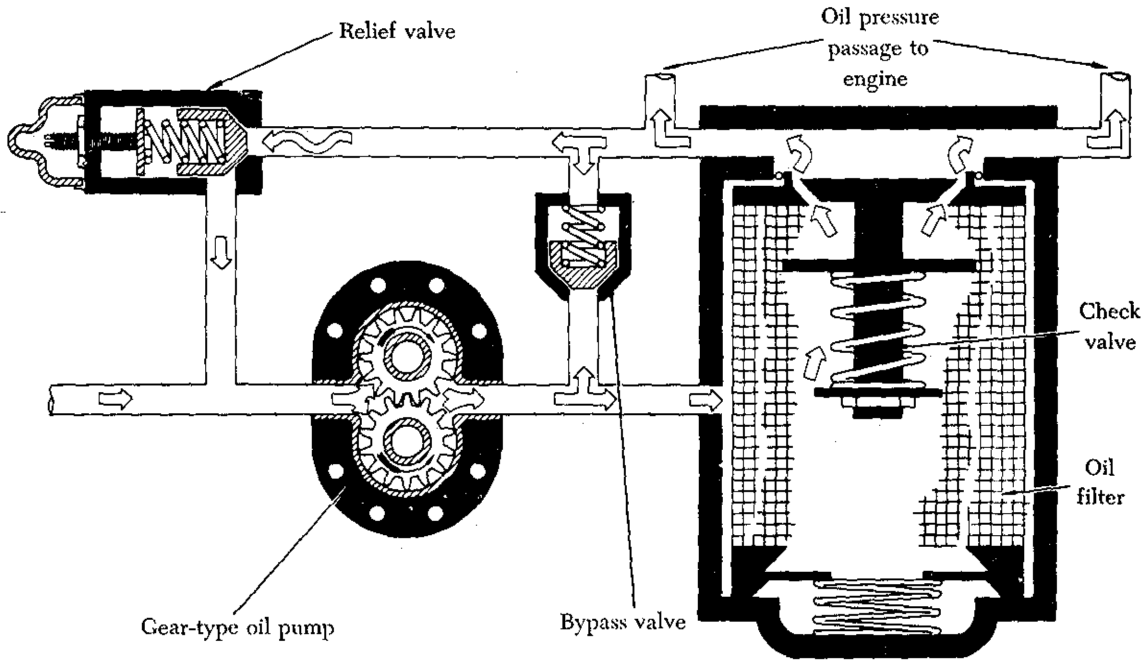


FIGURE 6–4. Engine oil pump and associated units.

fine-mesh screen, dirt, sediment, and other foreign matter are removed and settle to the bottom of the housing. At regular intervals the cover is removed and the screen and housing cleaned with a solvent.

The Cuno oil filter has a cartridge made of disks and spacers. A cleaner blade fits between each pair of disks. The cleaner blades are stationary, but the disks rotate when the shaft is turned. Oil from the pump enters the cartridge well that surrounds the cartridge and passes through the spaces between the closely spaced disks of the cartridge, then through the hollow center, and on to the engine. Any foreign particles in the oil are deposited on the outer surface of the cartridge. When the cartridge is rotated, the cleaner blades comb the foreign matter from the disks. The cartridge of the manually operated Cuno filter is turned by an external handle. Automatic Cuno filters have a hydraulic motor built into the filter head. This motor, operated by engine oil pressure, rotates the cartridge whenever the engine is running. There is a manual turning nut on the automatic Cuno filter for rotating the cartridge manually during inspections.

The Air-Maze filter contains a series of round, fine-meshed screens mounted on a hollow shaft. The oil from the pump enters the well, surrounds the screens, and then passes through them and the shaft before entering the engine. The carbon deposits that collect on the screens actually improve their filtering efficiency.

Oil Pressure Relief Valve

An oil pressure relief valve (figure 6–4), limits oil pressure to a predetermined value, depending on the installation. The oil pressure must be sufficiently high to ensure adequate lubrication of the engine and its accessories at high speeds and powers. On the other hand, the pressure must not be too high, as leakage and damage to the oil system may result. The oil pressure is adjusted by removing an acorn-shaped cap, loosening the locknut, and turning the adjusting screw. On most aircraft engines, turning the screw clockwise increases the tension of the spring that holds the relief valve on its seat and increases the oil pressure; turning the adjusting screw counterclockwise decreases the spring tension and lowers the pressure. The exact procedure for adjusting the oil pressure and the factors that will vary an oil pressure setting are included in applicable manufacturer's instructions.

Oil Pressure Gage

Usually the oil pressure gage indicates the pressure at which the oil enters the engine from the pump. This gage warns of possible engine failure caused by an exhausted oil supply, failure of the oil pump, burned-out bearings, ruptured oil lines, or other causes that may be indicated by a loss of oil pressure.

One type of oil pressure gage uses a Bourdon-tube mechanism that measures the difference between oil pressure and cabin (atmospheric) pressure. This gage is constructed the same as other Bourdon-type gages except that it has a small restriction built into the instrument case or into the nipple connection leading to the Bourdon tube. This restriction prevents the surging action of the oil pump from damaging the gage or causing the pointer to oscillate too violently with each pressure pulsation. The oil pressure gage has a scale ranging from zero to 200, or from zero to 300 p.s.i. Operation range markings are placed on the cover glass, or the face of the gage, to indicate the safe range of oil pressure for a given installation.

A dual-type oil pressure gage is available for use on multi-engine aircraft. The dual indicator contains two Bourdon tubes, housed in a standard instrument case, one tube being used for each engine. The connections extend from the back of the case to each engine. There is one common movement assembly, but the moving parts function independently. In some installations, the line leading from the engine to the pressure gage is filled with light oil. Since the viscosity of this oil will not vary much with changes in temperature, the gage will respond better to changes in oil pressure. In time, engine oil will mix with some of the light oil in the line to the transmitter, and during cold weather, the thicker mixture will cause sluggish instrument readings. To correct this condition, the gage line must be disconnected, drained, and refilled with light oil.

The trend is toward electrical transmitters and indicators for oil- and fuel-pressure-indicating systems in all aircraft. In this type of indicating system, the oil pressure being measured is applied to the inlet port of the electrical transmitter, where it is conducted to a diaphragm assembly by a capillary tube. The motion produced by the diaphragm's expansion and contraction is amplified through a lever and gear arrangement. The gear varies the electrical value of the indicating circuit, which, in turn, is reflected on the indicator in the cockpit. This type of indicating system replaces long fluid-filled tubing lines with an almost weightless piece of wire.

When the circulating oil has performed its function of lubricating and cooling the moving parts of the engine, it drains into the sumps in the lowest parts of the engine. Oil collected in these sumps is "picked up" by gear or gerotor-type scavenger pumps as quickly as it accumulates. These pumps have a greater capacity than the pressure pump. In dry sump engines, this oil leaves the engine, passes through the oil temperature regulator, and returns to the supply tank.

Oil Temperature Regulator

As discussed previously, the viscosity of the oil varies with its temperature. Since the viscosity affects its lubricating properties, the temperature at which the oil enters an engine must be held within close limits. Generally, the oil leaving an engine must be cooled before it is re-circulated. Obviously, the amount of cooling must be controlled if the oil is to return to the engine at the correct temperature. The oil temperature regulator, located in the return line to the tank, provides this controlled cooling. As the name implies, this unit regulates the temperature by either cooling the oil or passing it on to the tank without cooling, depending on the temperature at which it leaves the engine. The regulator *consists of two main parts:* (1) A cooler and (2) an oil control valve (see figure 6–2). The cooler transfers the heat from the oil to the air, while the control valve regulates the flow of oil through the cooler.

Indicating Oil Temperature

In dry-sump lubricating systems the oil temperature bulb may be anywhere in the oil inlet line between the supply tank and the engine. Oil systems for wet-sump engines have the temperature bulb located where it senses oil temperature after the oil passes through the oil cooler. In either system the bulb is located so that it measures the temperature of the oil before it enters the engine's hot sections.

An oil temperature gage in the cockpit is connected to the oil temperature bulb by electrical leads. The oil temperature will be indicated on the gage. Any malfunction of the oil cooling system will appear as an abnormal reading.

Oil flow in the system shown in figure 6–2 can be traced from the oil outlet fitting of the tank. The next units through which oil must flow to reach the engine are the drain valve and the firewall shutoff valve. The drain valve in this installation is a manual, two-position valve. It is located in the lowest part of the oil inlet line to the engine to permit complete drainage of the tank and its inlet supply line. The firewall shutoff valve is an electric motor-driven gate valve installed in the inlet oil line at the firewall of the nacelle. This valve shuts off the oil supply when there is a fire, when there is a break in the oil supply line, or when engine maintenance is performed that requires the oil to be shut off. In some aircraft the firewall shutoff valves for the oil system, fuel system, and hydraulic system are controlled by a single switch or mechanical linkage; other systems have separate control switches for each valve.

Oil Cooler

The cooler (figure 6–5), either cylindrical or elliptical shaped, consists of a core enclosed in a double-walled shell. The core is built of copper or aluminum tubes with the tube ends formed to a hexagonal shape and joined together in the honeycomb effect shown in figure 6–5. The ends of the copper tubes of the core are soldered, whereas aluminum tubes are brazed or mechanically joined. The tubes touch only at the ends so that a space exists between them along most of their lengths. This allows oil to flow through the spaces between the tubes while the cooling air passes through the tubes.

The space between the inner and outer shells is known as the annular or bypass jacket. Two paths are open to the flow of oil through a cooler. From the inlet it can flow halfway around the bypass jacket, enter the core from the bottom, and then

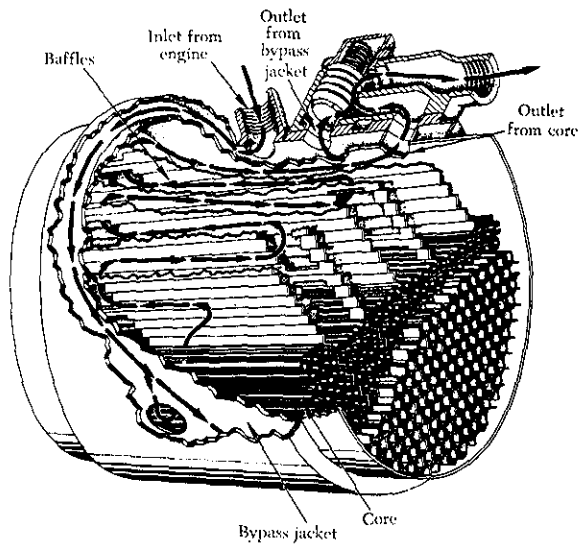


FIGURE 6–5. Oil cooler.

pass through the spaces between the tubes and out to the oil tank. This is the path the oil follows when it is hot enough to require cooling. As the oil flows through the core, it is guided by baffles, which force the oil to travel back and forth several times before it reaches the core outlet. The oil can also pass from the inlet completely around the bypass jacket to the outlet without passing through the core. Oil follows this bypass route when the oil is cold or when the core is blocked with thick, congealed oil.

Flow Control Valve

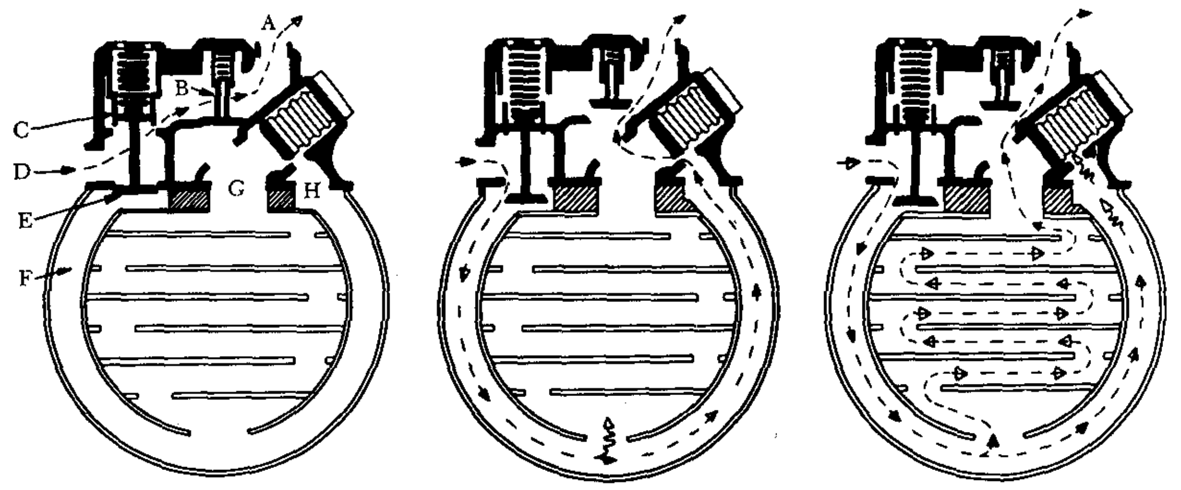
The flow control valve determines which of the two possible paths the oil will take through a cooler. There are two openings in a flow control valve which fit over the corresponding outlets at the top of the cooler. When the oil is cold, a bellows within the flow control contracts and lifts a valve from its seat. Under this condition, oil entering the cooler has a choice of two outlets and two paths. Following the path of least resistance, the oil flows around the jacket and out past the thermostatic valve to the tank. This allows the oil to warm up quickly and, at the same time, heats the oil in the core. As the oil warms up and reaches its operating temperature, the bellows of the thermostat expands and closes the outlet from the bypass jacket. The oil must now flow through the core into an opening in the base of the control valve, and out to the tank. No matter which path it takes through the cooler, the oil always flows over the bellows of the thermostatic valve.

Surge Protection Valves

When oil in the system is congealed, the scavenger pump may build up a very high pressure in the oil return line. To prevent this high pressure from bursting the oil cooler or blowing off the hose connections, some aircraft have surge, protection valves in the engine lubrication systems.

One type of surge valve (figure 6–6) is incorporated in the oil cooler flow control valve; another type is a separate unit in the oil return line.

The surge protection valve (figure 6–6) incorporated in a flow control valve is the more common type. Although this flow control valve differs from the one just described, it is essentially the same except for the surge protection feature. The high-pressure operation condition is shown in figure 6–6, where the high oil pressure at the control valve inlet has forced the surge valve (C) upward. Note how this movement has opened the surge valve and, at the same time, seated the poppet valve (E). The closed poppet valve prevents oil from entering the cooler proper; therefore, the scavenge oil passes directly to the tank through outlet (A) without passing through either the cooler bypass jacket or the core. When the pressure drops to a safe value, the spring forces the surge and poppet valves downward, closing the surge valve (C) and opening the poppet



Surge condition — Cold oil flow — Hot oil flow

A. Control valve outlet
B. Check valve
C. Surge valve
D. Control valve inlet
E. Poppet valve
F. Bypass jacket
G. Core outlet
H. Bypass jacket outlet

FIGURE 6–6. Control valve with surge protection.

valve (E). Oil then passes from the control valve inlet (D), through the open poppet valve, and into the bypass jacket (F). The thermostatic valve, according to oil temperature, then determines oil flow either through the bypass jacket to port (H) or through the core to port (G). The check valve (B) opens to allow the oil to reach the tank return line.

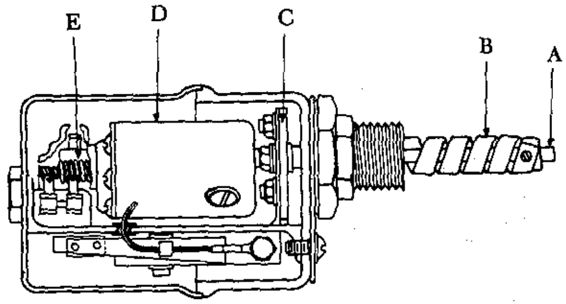
Airflow Controls

By regulating the airflow through the cooler, the temperature of the oil can be controlled to fit various operating conditions. For example, the oil will reach operating temperature more quickly if the airflow is cut off during engine warmup. There are two methods in general use: one method employs shutters installed on the rear of the oil cooler, and the other uses a flap on the air-exit duct.

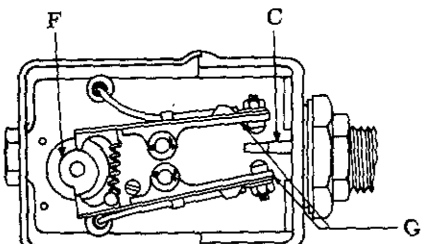
In some cases, the oil cooler air-exit flap is opened manually and closed by linkage attached to a cockpit lever. More often, the flap is opened and closed by an electric motor.

One of the most widely used automatic oil temperature control devices is the floating control thermostat that provides manual and automatic control of the oil inlet temperatures. With this type of control the oil cooler air-exit door is opened and closed automatically by an electrically operated actuator. Automatic operation of the actuator is determined by electrical impulses received from a controlling thermostat inserted in the oil pipe leading from the oil cooler to the oil supply tank. The actuator may be operated manually by an oil cooler air-exit door control switch. Placing this switch in the "open" or "closed" position produces a corresponding movement of the cooler door. Placing the switch in the "auto" position puts the actuator under the automatic control of the floating control thermostat (figure 6–7). The thermostat shown in figure 6–7 is adjusted to maintain a normal oil temperature so that it will not vary more than approximately 5° to 8° C., depending on the installation.

During operation, the temperature of the engine oil flowing over the bimetal element (B of figure 6–7) causes it to wind or unwind slightly. This movement rotates shaft (A) and the grounded center contact arm (C). As the grounded contact arm is rotated, it is moved toward either the open or closed floating contact arm (G). The two floating contact arms are oscillated by the cam (F), which is continuously rotated by an electric motor (D) through a gear train (E). When the grounded center contact arm is positioned by the bimetal element so that it will touch one of the floating contact arms, an electric circuit to the oil cooler exit-flap actuator motor is completed, causing the actuator to operate and position the oil cooler air-exit flap.



Top view

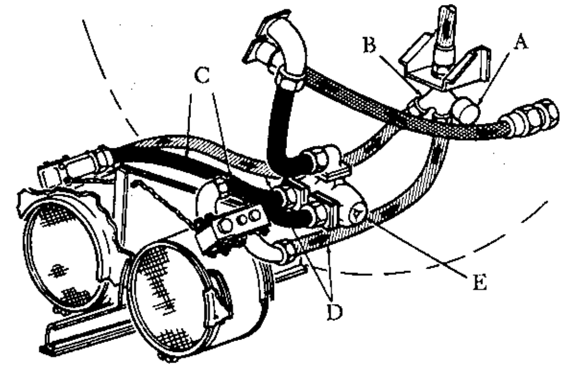


Side view

A. Shaft
B. Bimetal element
C. Grounded center contact arm
D. Electric motor
E. Gear train
F. Cam
G. Floating contact arm

FIGURE 6–7. Floating control thermostat.

In some lubrication systems, dual oil coolers are used. If the typical oil system previously described is adapted to two oil coolers, the system will be modified to include a flow divider, two identical coolers and flow regulators, dual air-exit doors, a two-door actuating mechanism, and a Y-fitting, as shown in figure 6–8. Oil is returned from the engine through a single tube to the flow divider (E), where the return oil flow is divided equally into two tubes (C), one for each cooler. The coolers and regulators have the same construction and operation as the cooler and flow regulator just described. Oil from the coolers is routed through two tubes (D) to a Y-fitting, where the floating control thermostat (A) samples oil temperature and positions the two oil cooler air-exit doors through the use of a two-door actuating mechanism. From the Y-fitting the lubricating oil is returned to the tank, where it completes its circuit.



A. Floating control thermostat
B. Y-fitting
C. Inlet to cooler tubes
D. Outlet from cooler tubes
E. Flow divider

FIGURE 6–8. Dual oil cooler system.

INTERNAL LUBRICATION OF RECIPROCATING ENGINES

The lubricating oil is distributed to the various moving parts of a typical internal-combustion engine by one of the three following methods: (1) Pressure, (2) splash, or (3) a combination of pressure and splash.

Pressure Lubrication

In a typical pressure-lubrication system (figure 6–9), a mechanical pump supplies oil under pressure to the bearings throughout the engine. The oil flows into the inlet or suction side of the oil pump through a line connected to the tank at a point higher than the bottom of the oil sump. This prevents sediment which falls into the sump from being drawn into the pump. The pump forces the

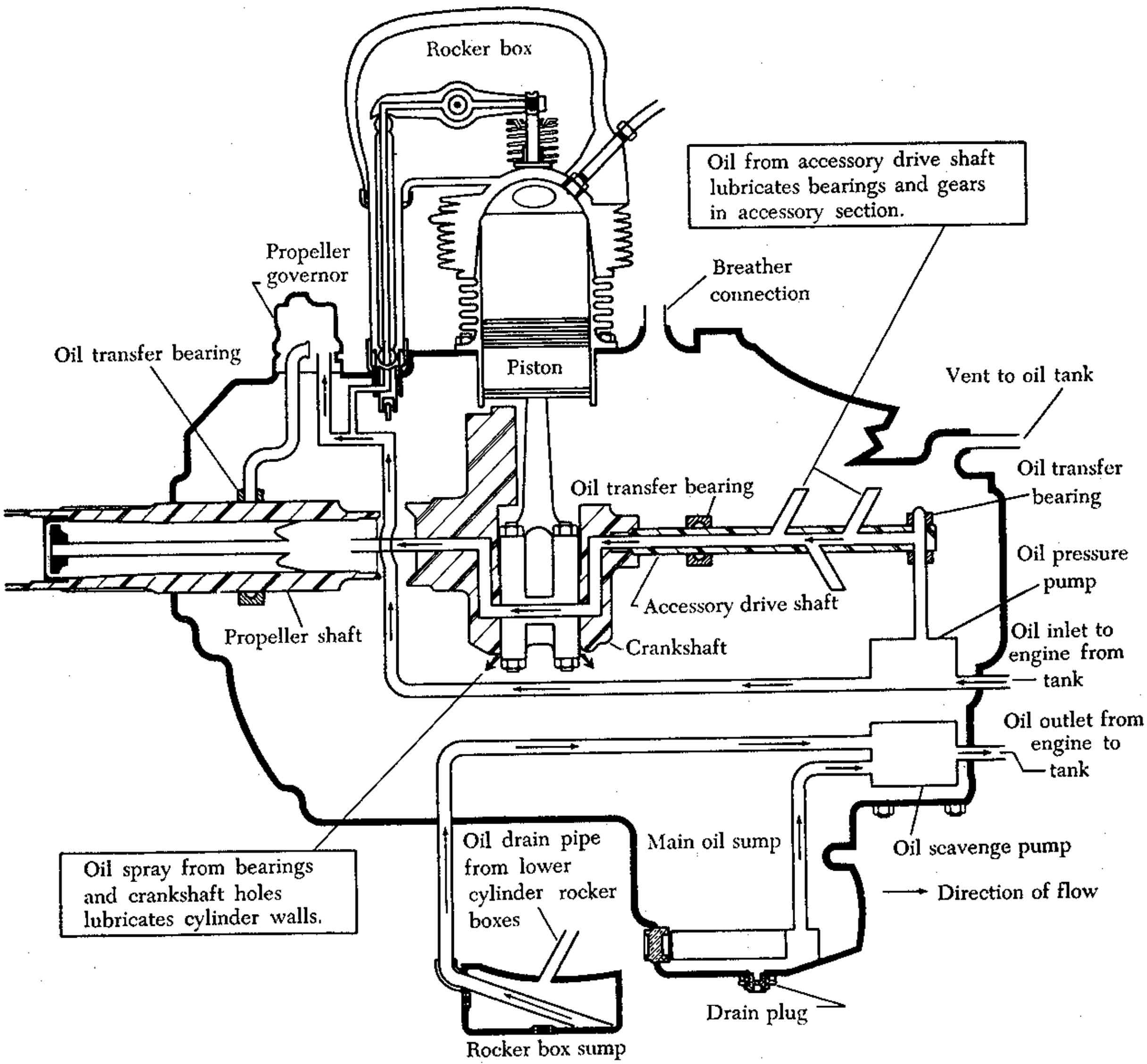


FIGURE 6–9. Schematic showing pressure dry-sump lubrication system.

oil into a manifold that distributes the oil through drilled passages to the crankshaft bearings and other bearings throughout the engine.

Oil flows from the main bearings through holes drilled in the crankshaft to the lower connecting rod bearings. Each of these holes through which the oil is fed is located so that the bearing pressure at the point will be as low as possible.

Oil reaches a hollow camshaft (in an in-line or opposed engine), or a camplate or camdrum (in a radial engine), through a connection with the end bearing, or the main oil manifold; it then flows out to the various camshaft, camdrum, or camplate bearings and the cams.

The engine cylinder surfaces receive oil sprayed from the crankshaft and also from the crankpin bearings. Since oil seeps slowly through the small crankpin clearances before it is sprayed on the cylinder walls, considerable time is required for enough oil to reach the cylinder walls, especially on a cold day when the oil flow is more sluggish. This is one of the chief reasons for diluting the engine oil with gasoline for cold weather starting.

Combination Splash-and-Pressure Lubrication

The pressure-lubrication system is the principal method of lubricating aircraft engines. Splash lubrication may be used in addition to pressure lubrition on aircraft engines, but it is never used by itself; hence, aircraft-engine lubrication systems are always either the pressure type or the combination pressure-and-splash type, usually the latter.

The advantages of pressure lubrication are:

(1) Positive introduction of oil to the bearings.
(2) Cooling effect caused by the large quantities of oil which can be (pumped) circulated through a bearing.
(3) Satisfactory lubrication in various attitudes of flight.

Wet-Sump Lubrication

A simple form of a wet-sump system is shown in figure 6–10. The system consists of a sump or pan in which the oil supply is contained. The level (quantity) of oil is indicated or measured by a vertical rod that protrudes into the oil from an elevated hole on top of the crankcase. In the bottom of the sump (oil pan) is a screen strainer having a suitable mesh or series of openings to strain undesirable particles from the oil and yet pass sufficient quantity to the inlet or (suction) side of the oil pressure pump.

The rotation of the pump, which is driven by the engine, causes the oil to pass around the outside of the gears in the manner illustrated in figure 6–4. This develops a pressure in the crankshaft oiling system (drilled passage-holes). The variation in the speed of the pump from idling to full-throttle operating range of the engine and the fluctuation of oil viscosity because of temperature changes are compensated by the tension on the relief valve spring. The pump is designed to create a greater pressure than probably will ever be required to compensate for wear of the bearings or thinning out of oil. The parts oiled by pressure throw a lubricating spray into the cylinder and piston assemblies. After lubricating the various units on which it sprays, the oil drains back into the sump and the cycle is repeated.

The main disadvantages of the wet-sump system are:

(1) The oil supply is limited by the sump (oil pan) capacity.
(2) Provisions for cooling the oil are difficult to arrange because the system is a self-contained unit.
(3) Oil temperatures are likely to be higher on large engines because the oil supply is so close to the engine and is continuously subjected to the operating temperatures.
(4) The system is not readily adaptable to inverted flying since the entire oil supply will flood the engine.

LUBRICATION SYSTEM MAINTENANCE PRACTICES

The following lubrication system practices are typical of those performed on small, single-engine aircraft. The oil system and components are those used to lubricate a 225 hp., six-cylinder, horizontally opposed, air-cooled engine.

The oil system is the dry-sump type, using a pressure lubrication system sustained by engine-driven, positive-displacement, gear-type pumps. The system (figure 6–11) consists of an oil cooler (radiator), a 3-gal. (U.S.) oil tank, oil pressure pump and scavenge pump, and the necessary interconnecting oil lines. Oil from the oil tank is pumped to the engine, where it circulates under pressure, then collects in the cooler, and is returned to the oil tank. A thermostat in the cooler controls oil temperature by allowing part of the oil to flow through the cooler and part to flow directly into the oil supply tank. This arrangement allows hot engine oil, with a temperature still below 65° C. (150° F.),

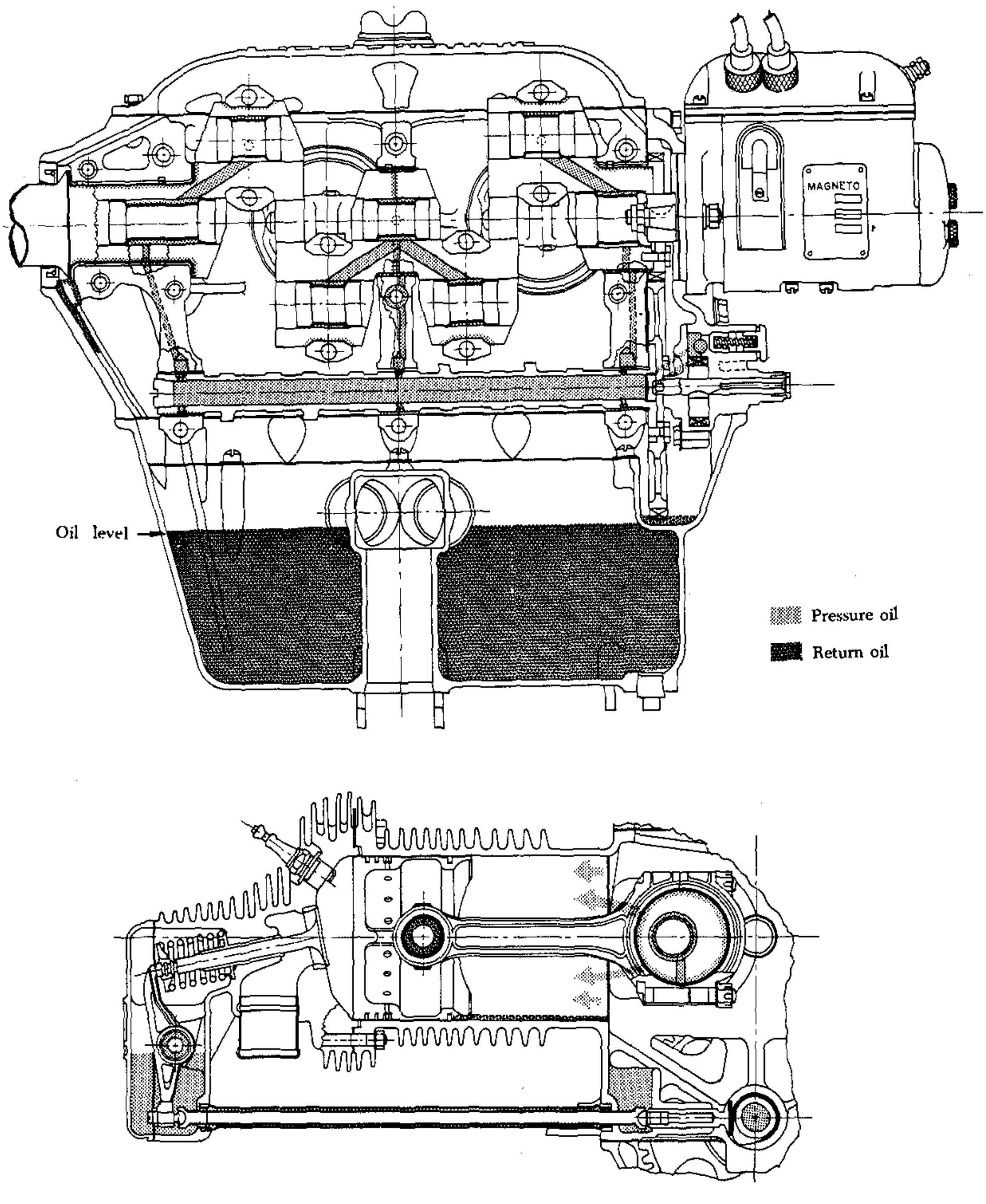


FIGURE 6–10. Schematic view of a typical wet-sump lubrication system.

to mix with the cold uncirculated oil in the tank. This raises the complete engine oil supply to operating temperature in a shorter period of time.

The oil tank, constructed of welded aluminum, is serviced through a filler neck located on the tank and equipped with a spring-loaded locking cap. Inside the tank a weighted, flexible rubber oil hose is mounted so that it is re-positioned automatically to ensure oil pickup during inverted maneuvers. A dipstick guard is welded inside the tank for the

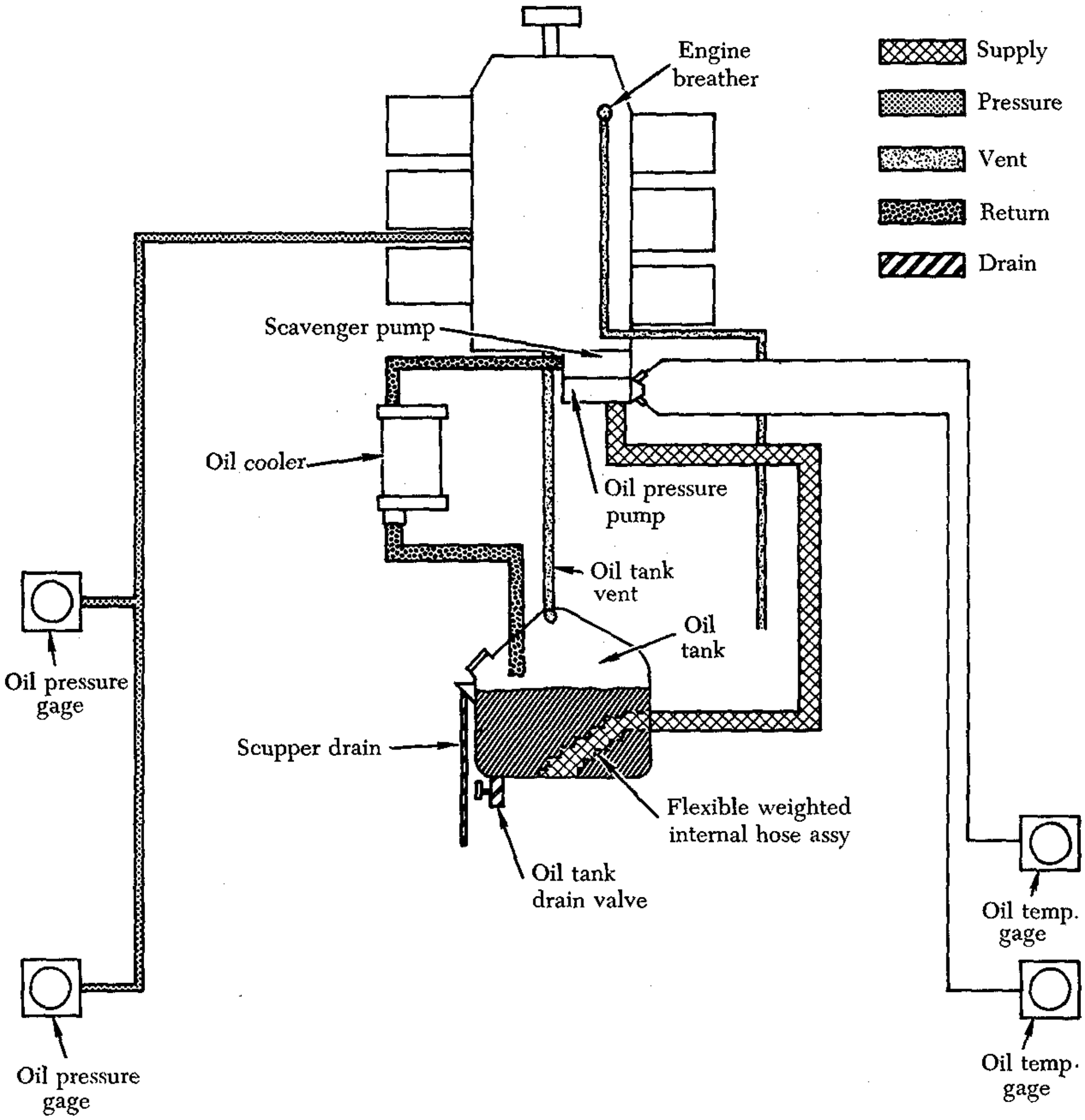


FIGURE 6–11. Oil system schematic.

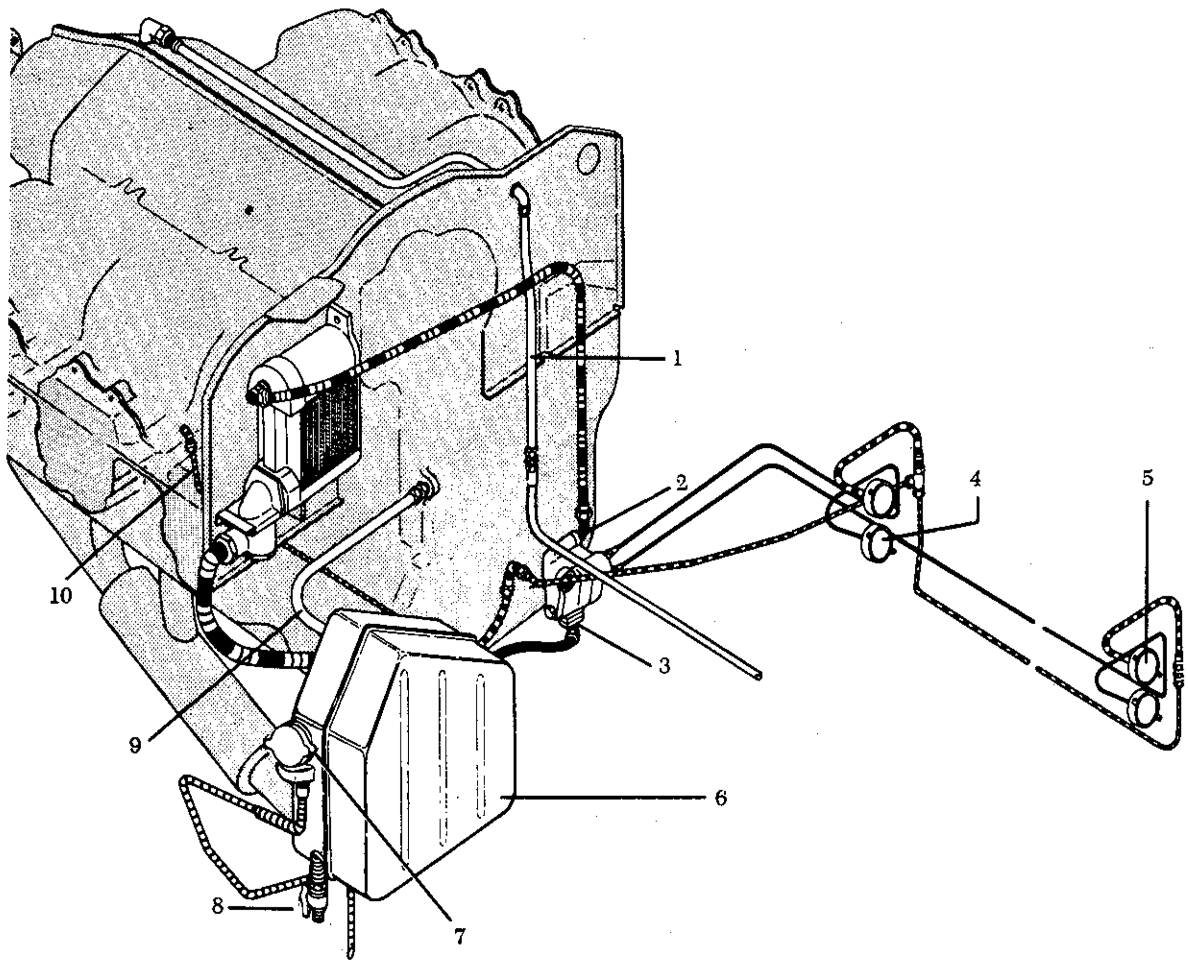
protection of the flexible oil hose assembly. During normal flight, the oil tank is vented to the engine crankcase by a flexible line at the top of the tank. However, during inverted flight the normal vent is covered or submerged below the oil level within the tank. Therefore, a secondary vent and check-valve arrangement is incorporated in the tank for inverted operation. During an inversion, when air in the oil tank reaches a certain pressure, the check valve in the secondary vent line will unseat and allow air to escape from the tank. This assures an uninterrupted flow of oil to the engine.

The location of the oil system components in relation to each other and to the engine is shown in figure 6–12.

Oil Tank

Repair of an oil tank usually requires that the tank be removed. The removal and installation procedures normally remain the same regardless of whether the engine is removed or not.

First, the oil must be drained. Most light aircraft



L E G E N D

Supply Pressure

Return Drain Vent

1. Engine breather
2. Oil outlet
3. Oil inlet
4. Oil temperature gage
5. Oil pressure gage
6. Oil tank
7. Oil filler
8. Oil tank drain
9. Oil tank vent line
10. Engine oil pressure line

FIGURE 6–12. Oil system perspective.

provide an oil drain similar to that shown in figure 6–13. On some aircraft the normal ground attitude of the aircraft may prevent the oil tank from draining completely. If the amount of undrained oil is excessive, the aft portion of the tank can be raised slightly after the tank straps have been loosened to complete the drainage.

After the oil tank has been drained, the cowl assembly is removed to provide access to the oil tank installation.

After disconnecting the oil inlet and vent lines (figure 6–14), the scupper drain hose and bonding wire can be removed.

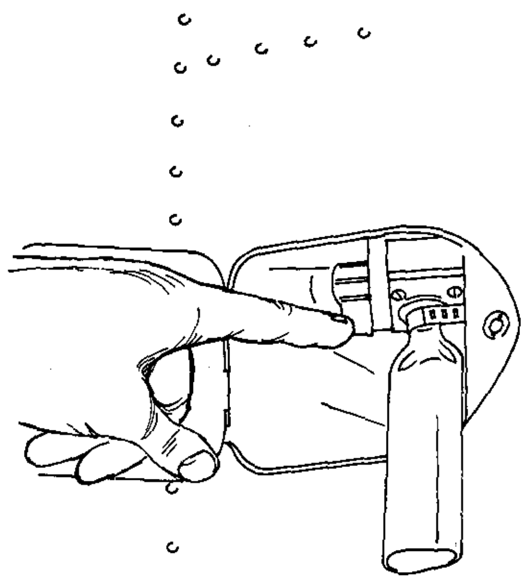


FIGURE 6–13. Oil tank drain.

The securing straps fitted around the tank can now be removed, as shown in figure 6–15. Any safety wire securing the clamp must be removed before the clamp can be loosened and the strap disconnected.

The tank can now be lifted out of the aircraft. The tank is re-installed by reversing the sequence used in the tank removal.

After installation, the oil tank should be filled to capacity (figure 6–16).

After the oil tank has been filled, the engine should be run for at least 2 minutes. Then the oil level should be checked, and, if necessary, sufficient oil should be added to bring the oil up to the proper level on the dipstick. (See figure 6–17.)

Oil Cooler

The oil cooler (figure 6–18) used with this aircraft's opposed-type engine is the honeycomb type. With the engine operating and an oil temperature below 65° C. (150° F.), an oil cooler bypass valve opens, allowing oil to bypass the core. This valve

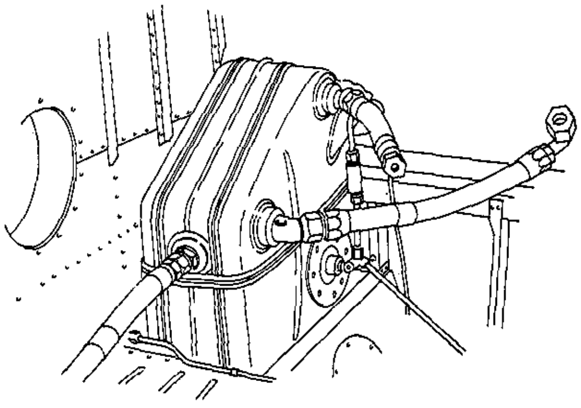


FIGURE 6–14. Disconnecting oil lines.

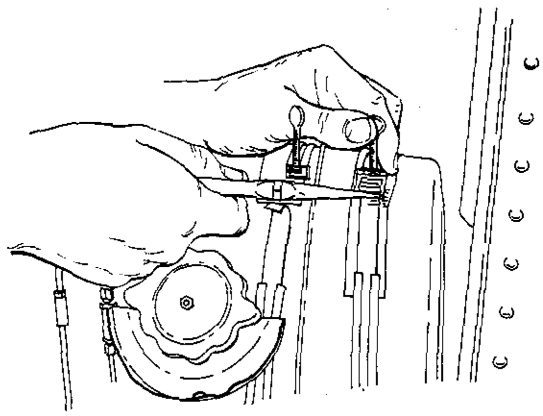


FIGURE 6–15. Removal of securing straps.

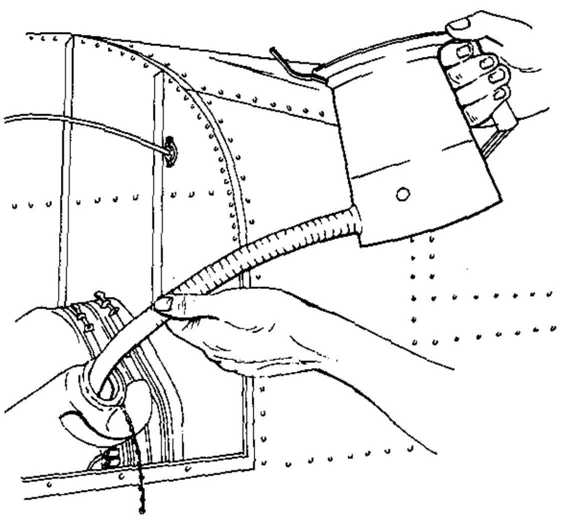


FIGURE 6–16. Filling an oil tank.

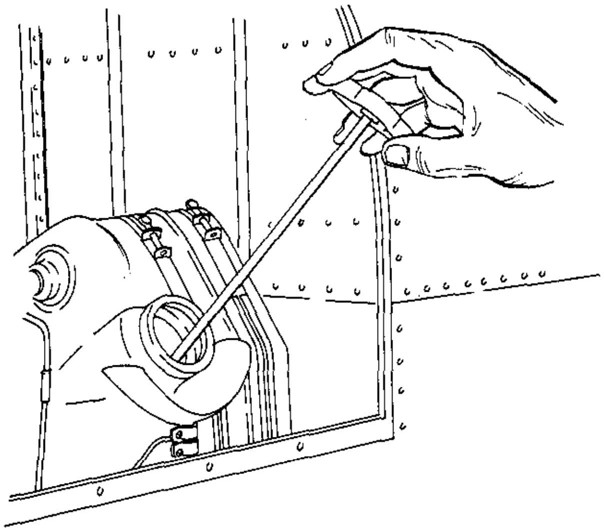


FIGURE 6–17. Checking oil level with dipstick.

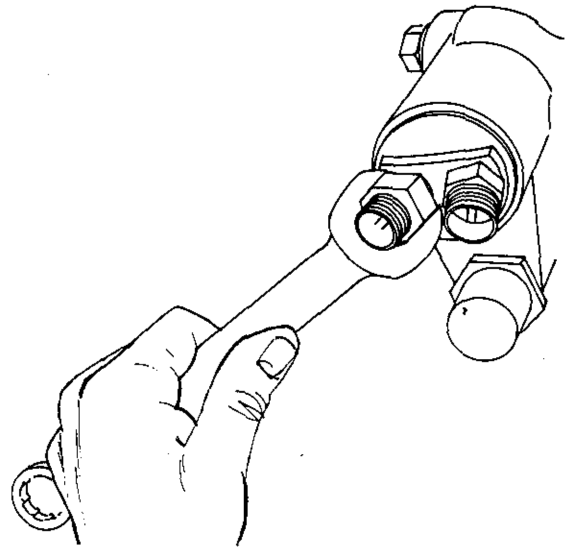


FIGURE 6–19. Removing oil temperature bulb.

begins to close when the oil temperature reaches approximately 65° C. (150° F.). When the oil temperature reaches 85° C. (185° F.), ±2° C., the valve is closed completely, diverting all oil flow through the cooler core.

Oil Temperature Bulbs

Most oil temperature bulbs are mounted in the pressure oil screen housing. They relay an indication of engine oil inlet temperature to the oil-temperature indicators mounted on the instrument panel. Temperature bulbs can be replaced by removing the safety wire and disconnecting the wire leads from the temperature bulbs; then remove the temperature bulbs, using the proper wrench, as shown in figure 6–19.

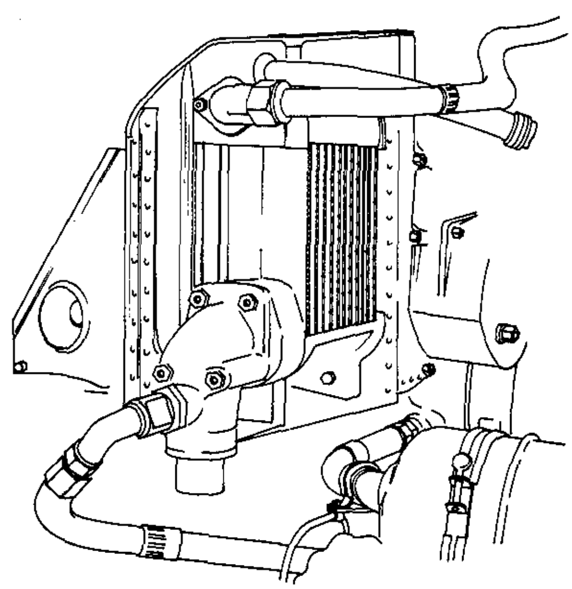


FIGURE 6–18. Oil cooler.

Pressure and Scavenge Oil Screens

Sludge will accumulate on the pressure and scavenge oil screens (figure 6–20) during engine operation. These screens must be removed, inspected, and cleaned at the intervals specified by the manufacturer.

Typical removal procedures include removing the safety devices and loosening the oil screen housing or cover plate. A suitable container should be provided to collect the oil that will drain from the filter housing or cavity. The container must be clean so that the oil collected in it can be examined for foreign particles. Any contamination already present in the container will give a false indication of the engine condition. This could result in a premature engine removal.

After the screens are removed, they should be inspected for contamination and for the presence of metal particles that may indicate engine internal failure. The screen must be cleaned prior to re-installing in the engine. In some cases it is necessary to disassemble the filter for inspection and cleaning. The manufacturer's procedures should be followed when disassembling and re-assembling an oil screen assembly.

When re-installing a filter, use new O-rings and gaskets, and tighten the filter housing or cover retaining nuts to the torque value specified in the

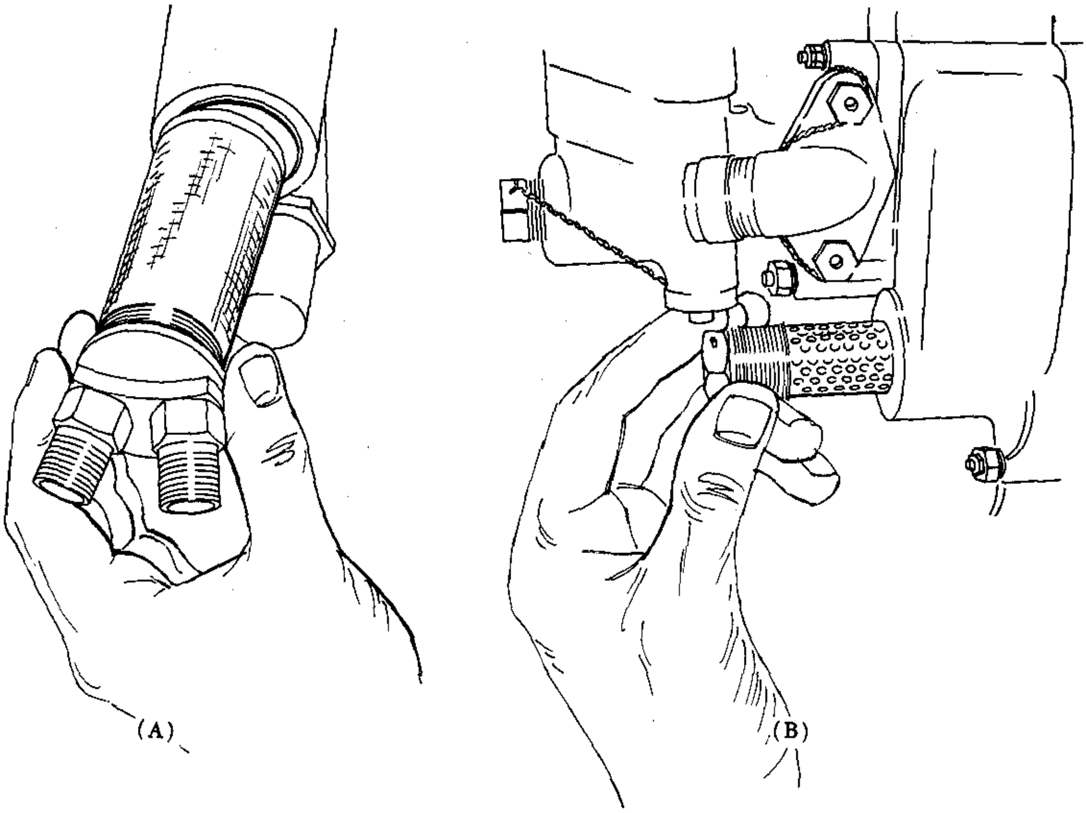


FIGURE 6–20. (A) Oil pressure screen and (B) Scavenge oil screen assembly.

applicable maintenance manual. Filters should be safetied as required.

Oil Pressure Relief Valve

An oil pressure relief valve limits oil pressure to the value specified by the engine manufacturer. Oil pressure settings vary from 35 p.s.i. to 90 p.s.i., depending on the installation. The oil pressure must be high enough to ensure adequate lubrication of the engine and accessories at high speeds and powers. On the other hand, the pressure must not be too high, since leakage and damage to the oil system may result. The oil pressure is adjusted by removing a cover nut, loosening a locknut, and turning the adjusting screw. (See figure 6–21.) Turn the adjusting screw clockwise to increase the pressure, or counterclockwise to decrease the pressure. Make the pressure adjustments while the engine is idling and tighten the adjustment screw locknut after each adjustment. Check the oil pressure reading while the engine is running at the r.p.m. specified in the manufacturer's maintenance manual. This may be from 1,900 r.p.m. to 2,300 r.p.m. The oil pressure reading should be between the limits prescribed by the manufacturer.

Draining Oil

Oil, in service, is constantly exposed to many harmful substances that reduce its ability to protect moving parts. The main contaminants are:

(1) Gasoline.
(2) Moisture.
(3) Acids.
(4) Dirt.
(5) Carbon.
(6) Metallic particles.

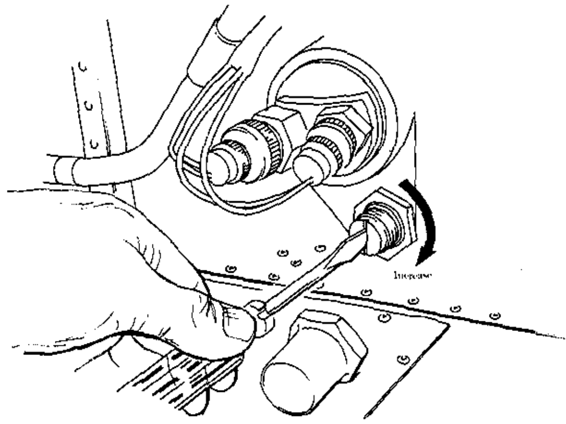


FIGURE 6–21. Oil pressure relief valve adjustment.

Because of the accumulation of these harmful substances, common practice is to drain the entire lubrication system at regular intervals and refill with new oil. The time between oil changes varies with each make and model aircraft and engine combination.

Troubleshooting Oil Systems

The outline of malfunctions and their remedies, listed in table 9, can expedite troubleshooting of the lubrication system. The purpose of this section is to present typical troubles. It is not intended to imply that any of the troubles are exactly as they may be in a particular airplane.

REQUIREMENTS FOR TURBINE ENGINE LUBRICANTS

There are many requirements for turbine engine lubricating oils, but because of the small number of moving parts and the complete absence of reciprocating motion, the lubrication problems are less complex in the turbine engine than in the reciprocating engine. Because of the absence of reciprocating motion, plus the use of ball and roller bearings, the turbine engine uses a less viscous lubricant. The turboprop engine, while using essentially the same type of oil as the turbojet, must use a higher viscosity oil because of the higher bearing pressures introduced by the highly loaded propeller reduction gearing.

Gas turbine engine oil must have a high viscosity for good load-carrying ability but must also be of sufficiently low viscosity to provide good flow ability. It must also be of low volatility to prevent loss by evaporation at the high altitudes at which the engines operate. In addition, the oil should not foam and should be essentially nondestructive to

TABLE 9. Oil System Troubleshooting Procedures.

TROUBLE	ISOLATION PROCEDURE	REMEDY
1. Excessive Oil Consumption.		
Oil line leakage.	Check external lines for evidence of oil leakage.	Replace or repair defective lines.
Accessory seal leakage.	Check for leak at accessories immediately after engine operation.	Replace accessory and/or defective accessory oil seal.
Low grade of oil.		Fill tank with proper grade oil.
Failing or failed bearing.	Check sump and oil pressure pump screen for metal particles.	Replace engine if metal particles are found.
2. High or Low Indicated Oil Pressure.		
Defective pressure gage.	Check indicator.	Replace indicator if defective.
Improper operation of oil pressure relief valve.	Erratic pressure indications either excessively high or low.	Remove, clean, and inspect relief valve.
Inadequate oil supply.	Check oil quantity.	Fill oil tank.
Diluted or contaminated oil.		Drain engine and tank; refill tank.
Clogged oil screen.		Remove and clean oil screen.
Oil viscosity incorrect.	Make sure correct oil is being used.	Drain engine and tank; refill tank.
Oil pump pressure relief valve adjustment incorrect.	Check pressure relief valve adjustment.	Make correct adjustment on oil pump pressure relief valve.
3. High or Low Indicated Oil Temperature.		
Defective temperature gage.	Check indicator.	Replace indicator if defective.
Inadequate oil supply.	Check oil quantity.	Fill oil tank.
Diluted or contaminated oil.		Drain engine and tank; refill tank.
Obstruction in oil tank.	Check tank.	Drain oil and remove obstruction.
Clogged oil screen.		Remove and clean oil screens.
Obstruction in oil cooler passages.	Check cooler for blocked or deformed passages.	Replace oil cooler if defective.
4. Oil Foaming.		
Diluted or contaminated oil.		Drain engine and tank; refill tank.
Oil level in tank too high.	Check oil quantity.	Drain excess oil from tank.

natural or synthetic rubber seals in the lubricating system. Also, with high-speed antifriction bearings, the formation of carbons or varnishes must be held to a minimum.

The many requirements for lubricating oils are met in the synthetic oils developed specifically for turbine engines. Synthetic oil has two principal advantages over petroleum oil. It has less tendency to deposit lacquer and coke and less tendency to evaporate at high temperature. Its principal disadvantage is that it tends to blister or remove paint wherever it is spilled. Painted surfaces should be wiped clean with a petroleum solvent after spillage.

Oil change intervals for turbine engines vary widely from model to model, depending on the severity of the oil temperature conditions imposed by the specific airframe installation and engine configuration. The applicable manufacturer's instructions should be followed.

Synthetic oil for turbine engines usually is supplied in sealed 1-quart or 1-gallon metal cans. Although this type of container was chosen to minimize contamination, it has often been found necessary to filter the oil to remove metal slivers, can sealants, etc., which may occur as a result of opening the can.

Some oil grades for use in turbojet engines may contain oxidation preventives, load-carrying additives, and substances that lower the pour point, in addition to synthetic chemical-base materials.

TURBINE ENGINE LUBRICATION SYSTEMS

Both wet- and dry-sump lubrication systems are used in gas turbine engines. Most turbojet engines are of the axial-flow configuration, and use a dry-sump lubrication system. However, some turbine engines are equipped with a combination dry- and wet-type of lubrication system.

Wet-sump engines store the lubricating oil in the engine proper, while dry-sump engines utilize an external tank mounted most generally on the engine or somewhere in the aircraft structure near the engine. To ensure proper temperature, oil is routed through either an air-cooled or a fuel-cooled oil cooler.

The exhaust turbine bearing is the most critical lubricating point in a gas turbine engine because of the high temperature normally present. In some engines air cooling is used in addition to oil cooling the bearing which supports the turbine. Air cooling, when used, is furnished by a cooling air impeller mounted on the compressor shaft just aft of the main compressor. Also, some turbine wheels may have a circle of air-pumping vanes on their front side to cause air to flow over the turbine disk, which reduces heat radiation to the bearing surface. Axial-flow engines sometimes use compressor air to aid in cooling the turbine or its supporting bearing. This bleed-air, as it is called, is usually bled off the fourth or fifth stage, since at this point air has enough pressure but has not yet become too warm (as the air is compressed, it becomes heated).

The use of cooling air on bearings and turbines eliminates the necessity of using oil coolers in the wet-sump lubrication systems, since a considerable amount of the heat normally present is dissipated by the cooling air rather than absorbed by the oil. Also, the use of cooling air substantially reduces the quantity of oil necessary to provide adequate cooling of the bearings. Engines that depend solely on lubricating oil for bearing cooling normally require oil coolers, although of a relatively small capacity. When an oil cooler is required, usually a greater quantity of oil is necessary to provide for circulation between the cooler and engine.

Turbojet Dry-Sump Lubrication

In a turbojet dry-sump lubrication system, the oil supply is carried in a tank mounted on the engine. With this type of system, a larger oil supply can be carried and the temperature of the oil can readily be controlled. An oil cooler usually is included in a dry-sump oil system (figure 6–22). This cooler may be air cooled or fuel cooled. The dry-sump oil system allows the axial-flow engines to retain their comparatively small diameter by designing the oil tank and the oil cooler to conform with the streamlined design of the engines.

The following component descriptions include most of those found in the various turbojet lubrication systems. However, since engine oil systems vary somewhat according to engine model and manufacturer, not all of these components will necessarily be found in any one system.

Although the dry-sump systems use an oil tank which contains most of the oil supply, a small sump usually is included on the engine to hold a small supply of oil. It usually contains the oil pump, the scavenge and pressure inlet strainers, scavenge return connection, pressure outlet ports, an oil filter, and mounting bosses for the oil pressure gage and temperature bulb connections.

A view of a typical oil tank is shown in figure 6–23. It is designed to furnish a constant supply of oil to the engine during any aircraft attitude. This is done by a swivel outlet assembly mounted inside the tank, a horizontal baffle mounted in the center

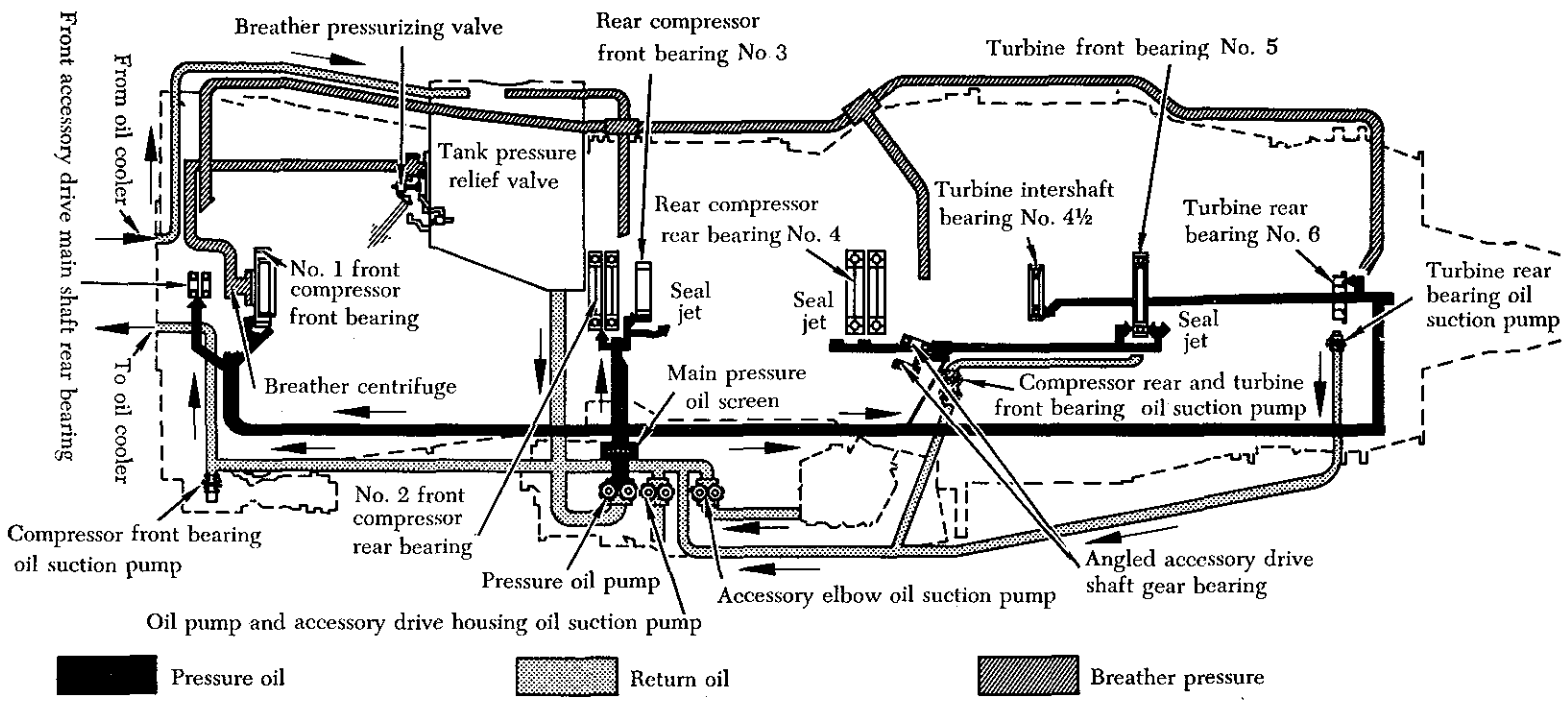


FIGURE 6–22. A turbojet dry-sump lubrication system.

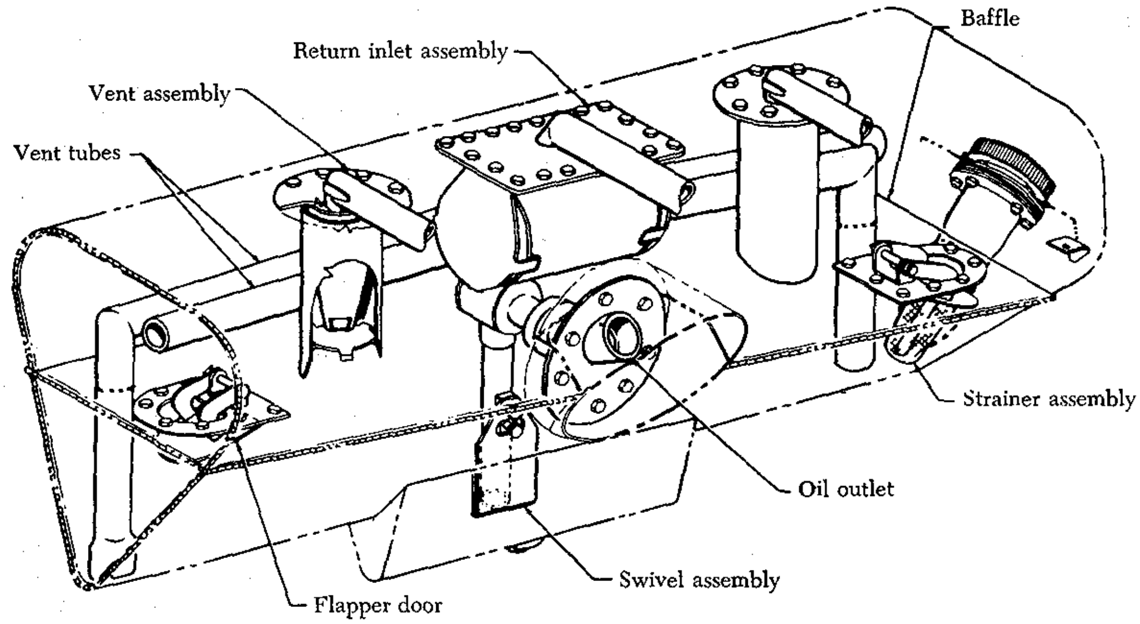


FIGURE 6–23. Oil tank.

of the tank, two flapper check valves mounted on the baffle, and a positive vent system.

The swivel outlet fitting is controlled by a weighted end, which is free to swing below the baffle. The flapper valves in the baffle are normally open; they close only when the oil in the bottom of the tank tends to rush to the top of the tank during decelerations. This traps the oil in the bottom of the tank where it is picked up by the swivel fitting. A sump drain is located in the bottom of the tank.

The vent system inside the tank (figure 6–23) is so arranged that the airspace is vented at all times even though oil may be forced to the top of the tank by deceleration of the aircraft.

All oil tanks are provided with expansion space. This allows for expansion of the oil after heat is absorbed from the bearings and gears and after the oil foams as a result of circulating through the system. Some tanks also incorporate a de-aerator tray for separating air from the oil returned to the top of the tank by the scavenger system. Usually these de-aerators are the "can" type in which oil enters at a tangent. The air released is carried out through the vent system in the top of the tank. In most oil tanks a pressure buildup is desired within the tank to assure a positive flow of oil to the oil pump inlet. This pressure buildup is made possible by running the vent line through an adjustable check relief valve. The check relief valve normally is set to relieve at about 4 p.s.i. pressure on the oil pump inlet.

Experience has shown there is little need for an oil dilution system. If the air temperature is abnormally low, the oil may be changed to a lighter grade. Some engines may provide for the installation of an immersion-type oil heater.

Oil Pump

The oil pump is designed to supply oil under pressure to the parts of the engine that require lubrication. Many oil pumps consist not only of a pressure supply element, but scavenge elements as well. However, there are some oil pumps which serve a single function; that is, they either supply or scavenge the oil. The number of pumping elements, both pressure and scavenge, will depend largely on the type and model of the engine. For instance, axial-flow engines have a long rotor shaft, which means that more bearings normally will be required for support than on a centrifugal-flow engine. Therefore, the oil pump elements for both supply and scavenge must be several in number or of larger capacity. In all types of pumps, the scavenge elements have a greater pumping capacity than the pressure element to prevent oil from collecting in the bearing sumps.

The pumps may be one of several types, each type having certain advantages and limitations. The three most common oil pumps are the gear, gerotor, and piston, the gear type being the most commonly used. Each of these pumps has several possible configurations.

The gear-type oil pump illustrated in figure 6–24 has only two elements, one for pressure oil and one for scavenging. However, some types of pumps may have several elements, two or more elements for scavenging and one or more for pressure.

A relief valve in the discharge side of the pump (figure 6–24) limits the output pressure of the pump by bypassing oil to the pump inlet when the outlet pressure exceeds a predetermined limit. Also shown is the shaft shear section, which causes the shaft to shear if the pump gears should seize.

The gerotor pump, like the gear pump, usually contains a single element for oil pressure and several elements for scavenging oil. Each of the elements, pressure and scavenge, is almost identical in shape; however, the capacity of the elements can be controlled by varying the size of the gerotor elements. For example, the pressure element may have a pumping capacity of 3.1 g.p.m. (gallon per minute) as compared to 4.25 g.p.m. capacity for the scavenge elements. Consequently, the pressure element is smaller, since the elements are all driven by a common shaft. The pressure is determined by engine r.p.m. with a minimum pressure at idling speed and maximum pressure at intermediate and maximum engine speeds.

A typical set of gerotor pumping elements is shown in figure 6–25. Each set of gerotors is separated by a steel plate, making each set an individual pumping unit consisting of an inner and an outer element. The small star-shaped inner element has external lobes that fit within and are matched with the outer element, which has internal lobes. The small element fits on and is keyed to the pump shaft and acts as a drive for the outer free-turning element. The outer element fits within a steel plate having an eccentric bore. In one engine model the oil pump has four elements, one for oil feed and three for scavenge. In some models, pumps have six elements, one for feed and five for scavenge. In

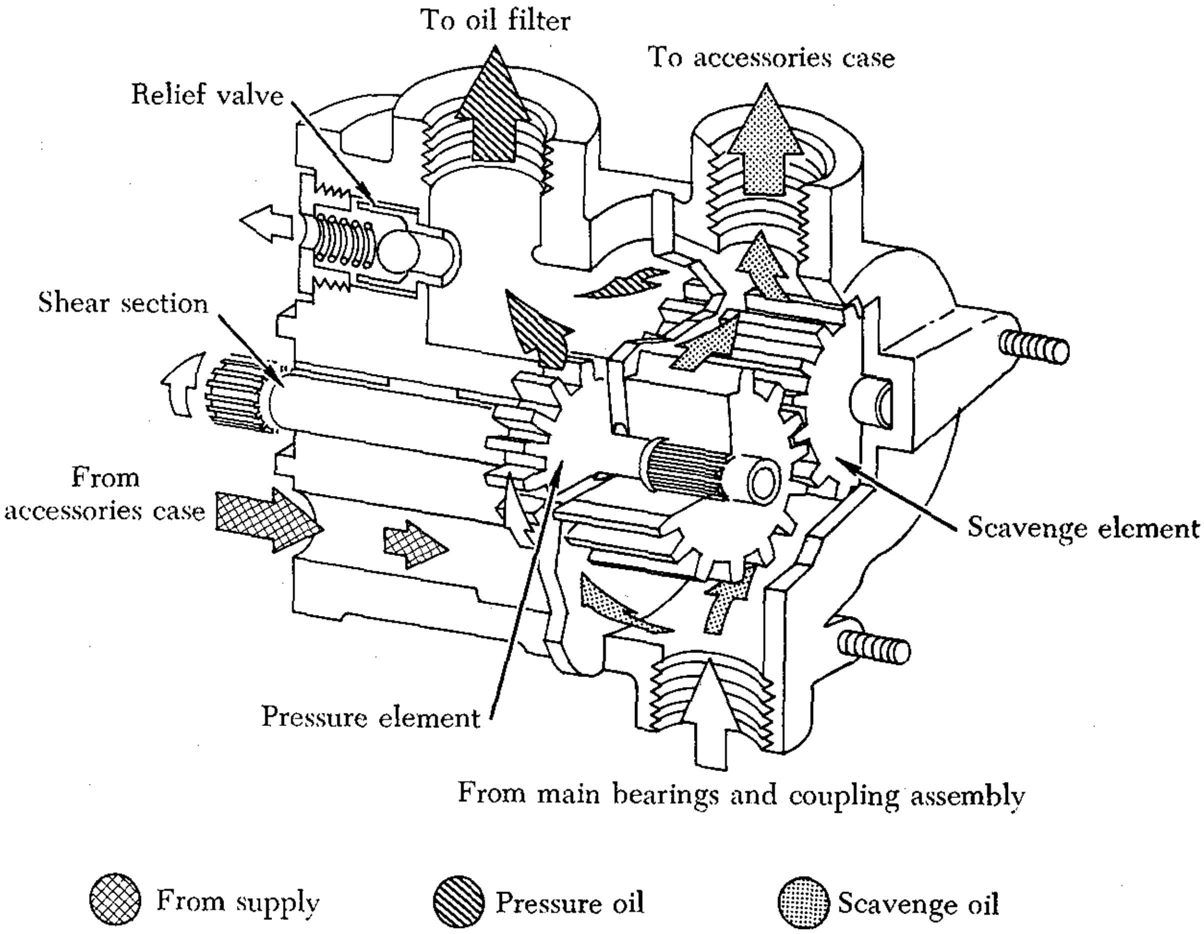


FIGURE 6–24. Cutaway view of gear oil pump.

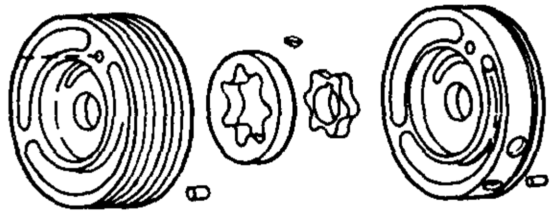


FIGURE 6–25. Typical gerotor pumping elements.

each case the oil flows as long as the engine shaft is turning.

The piston-type lubrication pump is a multiplunger type. The output of each piston supplies a separate jet. Oil drained from the points of lubrication is scavenged by a separate pump element and returned to the reservoir. The piston-type pump is used to a lesser extent than either of the other types.

Filters

Filters are an important part of the lubrication system, since they remove foreign particles that may be in the oil. This is particularly important in gas turbines, as very high engine speeds are attained, and the antifriction types of ball and roller bearings would become damaged quite rapidly if lubricated with contaminated oil. Also, there are usually a number of drilled or core passages leading to various points of lubrication. Since these passages are usually rather small, they are easily clogged.

There are several types of filters used for filtering the lubricating oil. The filtering elements come in a variety of configurations. Since it would be impractical to include every type, only the more common filter types are discussed.

One common type of oil filter uses a replaceable laminated paper element, such as those used in hydraulic systems. In another type the filter element is made up of a series of spacers and screens, as shown in figure 6–26. This filter is made up of a stack of metal disks covered with a screen and separated by spacers so that the oil can flow through the screens and out the outlet port of the strainer body.

Another type of filter, used as a main oil strainer, is shown in figure 6–27. The filtering element interior is made of stainless steel.

Each of the oil filters mentioned has certain advantages. In each case the filter selected is the one that best meets the individual needs of a particular engine. The filters discussed generally are used as main oil filters; that is, they strain the oil as it leaves the pump before being piped to the

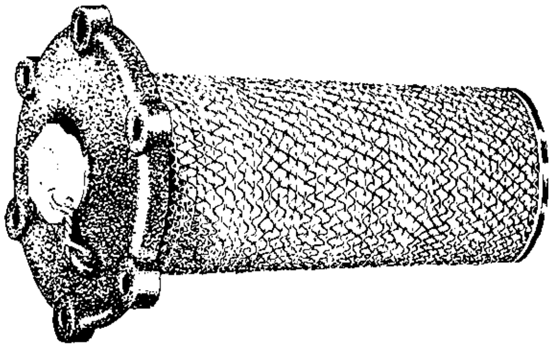


FIGURE 6–26. Spacers-and-screens oil filter.

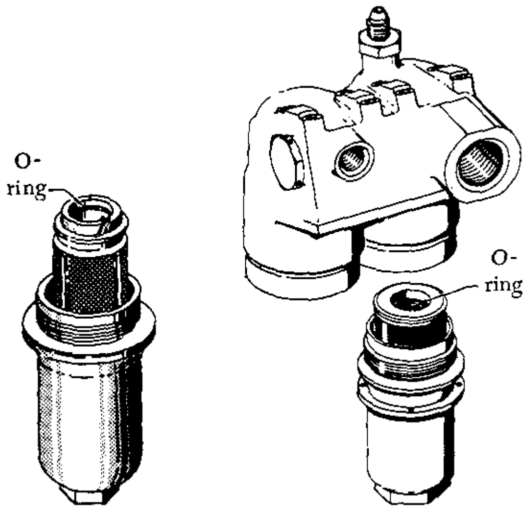


FIGURE 6–27. Filtering assembly.

various points of lubrication. In addition to the main oil filters, there are also secondary filters located throughout the system for various purposes. For instance, there may be a finger screen filter, which is sometimes used for straining scavenged oil. Also, there are fine-mesh screens, called "last chance" filters, for straining the oil just before it passes from the spray nozzles onto the bearing surfaces.

The components of a typical main oil filter include a housing, which has an integral relief (or bypass) valve and, of course, the filtering element.

The filter bypass valve prevents the oil flow from being stopped if the filter element becomes clogged. The bypass valve opens whenever a certain pressure is reached. If this occurs, the filtering action is lost, allowing unfiltered oil to be pumped to the bearings.

Oil Pressure Relief Valve

An oil pressure relief valve is included in the pressure oil line to limit the maximum pressure within the system. This valve is especially important if an oil cooler is incorporated in the system, since the coolers are easily ruptured because of their thin-wall construction. The relief valve is preset to relieve pressure and bypass the oil back to the inlet side of the oil pump whenever the pressure exceeds the preset limit.

Oil Jets

Oil jets (or nozzles) are located in the pressure lines adjacent to, or within, the bearing compartments and rotor shaft couplings. The oil from these nozzles is delivered in the form of an atomized spray. Some engines use an air-oil mist spray, which is produced by tapping high-pressure bleed-air from the compressor to the oil nozzle outlet. This method is considered adequate for ball and roller bearings; however, the solid oil spray method is considered the better of the two methods.

The oil jets are easily clogged because of the small orifice in their tips; consequently, the oil must be free of any foreign particles. If the last-chance filters in the oil jets should become clogged, bearing failure usually results, since nozzles are not accessible for cleaning except during engine overhaul. To prevent damage from clogged oil jets, main oil filters are checked frequently for contamination.

Lubrication System Gage Connections

Gage connection provisions are incorporated in the oil system for oil pressure and oil temperature. The oil pressure gage measures the pressure of the lubricant as it leaves the pump on its way to the oil jets.

Two of the most common methods of obtaining oil temperature indications are: (1) A thermocouple fitting in the oil line or (2) an oil temperature bulb inserted in the oil line.

The oil pressure gage connection is located in the pressure line between the pump and the various points of lubrication. The oil temperature gage connection usually is located in the pressure inlet to the engine.

Lubrication System Vents

Vents or breathers are lines or openings in the oil tanks or accessory cases of the various engines, depending on whether the engine has a dry- or wet-sump lubrication system.

The vent in an oil tank keeps the pressure within the tank from rising above or falling below that of the outside atmosphere. However, the vent may be routed through a check relief valve, which is preset to maintain a slight (approximately 4 p.s.i.) pressure on the oil to assure a positive flow to the oil pump inlet.

In the accessory case the vent (or breather) is a screen-protected opening, which allows accumulated air pressure within the accessory case to escape to the atmosphere. The scavenged oil carries air into the accessory case and this air must be vented; otherwise, the pressure buildup within the accessory case would stop the flow of oil draining from the bearing, thus forcing this oil past the rear bearing oil seal and into the compressor housing. Oil leakage could, of course, cause any of several results, the least of which would be the use of too much oil. A more serious result would occur if oil leakage were great enough to cause burning in the combustion area, which could cause turbine failure because of a hotspot.

The screened breathers usually are located in the front center of the accessory case to prevent oil leakage through the breather when the aircraft is in unusual flight attitudes. Some breathers may have a baffle to prevent oil leakage during flight maneuvers.

A vent which leads directly to the bearing compartment may be used in some engines. This vent equalizes pressure around the front bearing surface so that the lower pressure at the first compressor stage will not cause oil to be forced past the bearing rear oil seal into the compressor.

Lubrication System Check Valve

Check valves are sometimes installed in the oil supply lines of dry-sump oil systems to prevent reservoir oil from seeping (by gravity) through the oil pump elements and high-pressure lines into the engine after shutdown. Check valves, by stopping flow in an opposite direction, prevent accumulations of undue amounts of oil in the accessory gearbox, compressor rear housing, and combustion chamber. Such accumulations could cause excessive loading of the accessory drive gears during starts, contamination of the cabin pressurization air, or internal oil fires.

The check valves usually are the spring-loaded, ball-and-socket type, constructed for free flow of pressure oil. The pressure required to open these valves will vary, but the valves generally require from 2 to 5 p.s.i. to permit oil to flow to the bearings.

Lubrication System Thermostatic Bypass Valves

Thermostatic bypass valves are included in oil systems using an oil cooler. Although these valves may be called different names, their purpose is always to maintain proper oil temperature by varying the proportion of the total oil flow passing through the oil cooler. A cutaway view of a typical thermostatic bypass valve is shown in figure 6–28. This valve consists of a valve body, having two inlet ports and one outlet port, and a spring-loaded thermostatic element valve.

The valve is spring loaded because the pressure drop through the oil cooler could become too great because of denting or clogging of the cooler tubing. In such case, the valve will open, bypassing the oil around the cooler.

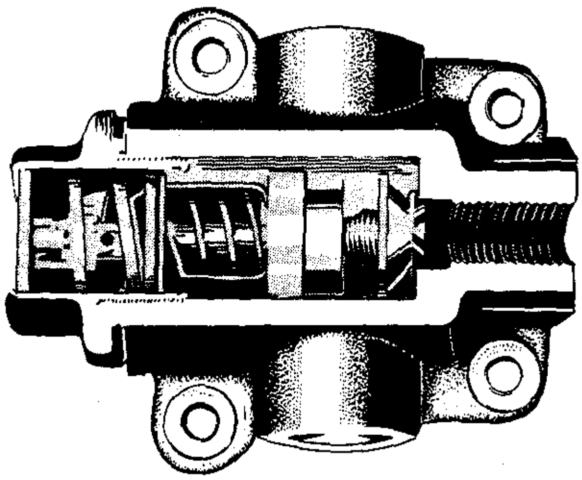


FIGURE 6–28. A typical thermostatic bypass valve.

Oil Coolers

Oil coolers are used in the lubricating systems of some turbine engines to reduce the temperature of the oil to a degree suitable for recirculation through the system.

Previous discussion has disclosed that oil coolers are not required in wet-sump lubrication systems because of the use of cooling air, which is forced around the turbine wheel and turbine bearings. This cooling air, furnished by an auxiliary impeller on the rotor shaft or by bleeding off compressor air, reduces the heat that normally would be absorbed by the oil. Another factor that further reduces oil heat in wet-sump systems is that the air entering the engine first flows around the accessory case, thus cooling the oil by cooling the reservoir.

Dry-sump lubrication systems require coolers for several reasons. First, air cooling of bearings by using compressor bleed-air is not as good as forced air cooling from the auxiliary impeller because of the heat present in compressor bleed-air. Second, the axial-flow engine normally will require a greater number of bearings, which means that more heat will be transferred to the oil. Third, the air entering the axial-flow engine does not flow around the oil reservoir as it does on the wet-sump system. Consequently, the oil cooler is the only means of dissipating the oil heat.

Two basic types of oil coolers in general use are the air-cooled oil cooler and the fuel-cooled oil cooler. The fuel-cooled oil cooler acts as a fuel/oil heat exchanger in that the fuel cools the oil and the oil heats the fuel. The air-cooled oil cooler normally is installed at the forward end of the engine. It is similar in construction and operation to the air-cooled cooler used on reciprocating engines.

Fuel/Oil Heat Exchanger

The fuel/oil heat exchanger illustrated in figure 6–29 is designed to cool the hot oil and to preheat the fuel for combustion. Fuel flowing to the engine must pass through the heat exchanger; however, there is a thermostatic valve which controls the oil flow, and the oil may bypass the cooler if no cooling is needed. The fuel/oil heat exchanger consists of a series of joined tubes with an inlet and outlet port. The oil enters the inlet port, moves around the fuel tubes, and goes out the oil outlet port.

The heat exchanger cooler has the advantage of allowing the engine to retain its small frontal area. Since the cooler is mounted on the engine, it offers little drag.

TYPICAL DRY-SUMP LUBRICATION SYSTEM

The turbojet lubrication system shown in figure 6–30 is representative of turbine engines using a dry-sump system. The lubrication system is of a self-contained, high-pressure design. It consists of the pressure, scavenge, and breather subsystems.

The pressure system supplies oil to the main engine bearings and to the accessory drives. The scavenger system returns the oil to the engine oil tank, which usually is mounted on the compressor case. It is connected to the inlet side of the pressure oil pump and completes the oil flow cycle. A breather system connecting the individual bearing compartments and the oil tank with the breather pressurizing valve completes the engine lubrication system.

Oil Pressure System Maintenance

The oil pressure branch of the engine lubrication system (figure 6–30) is pressurized by a gear-type pressure pump located in the left side of the oil pump and accessory drive housing. The pressure pump receives engine oil at its lower (inlet) side

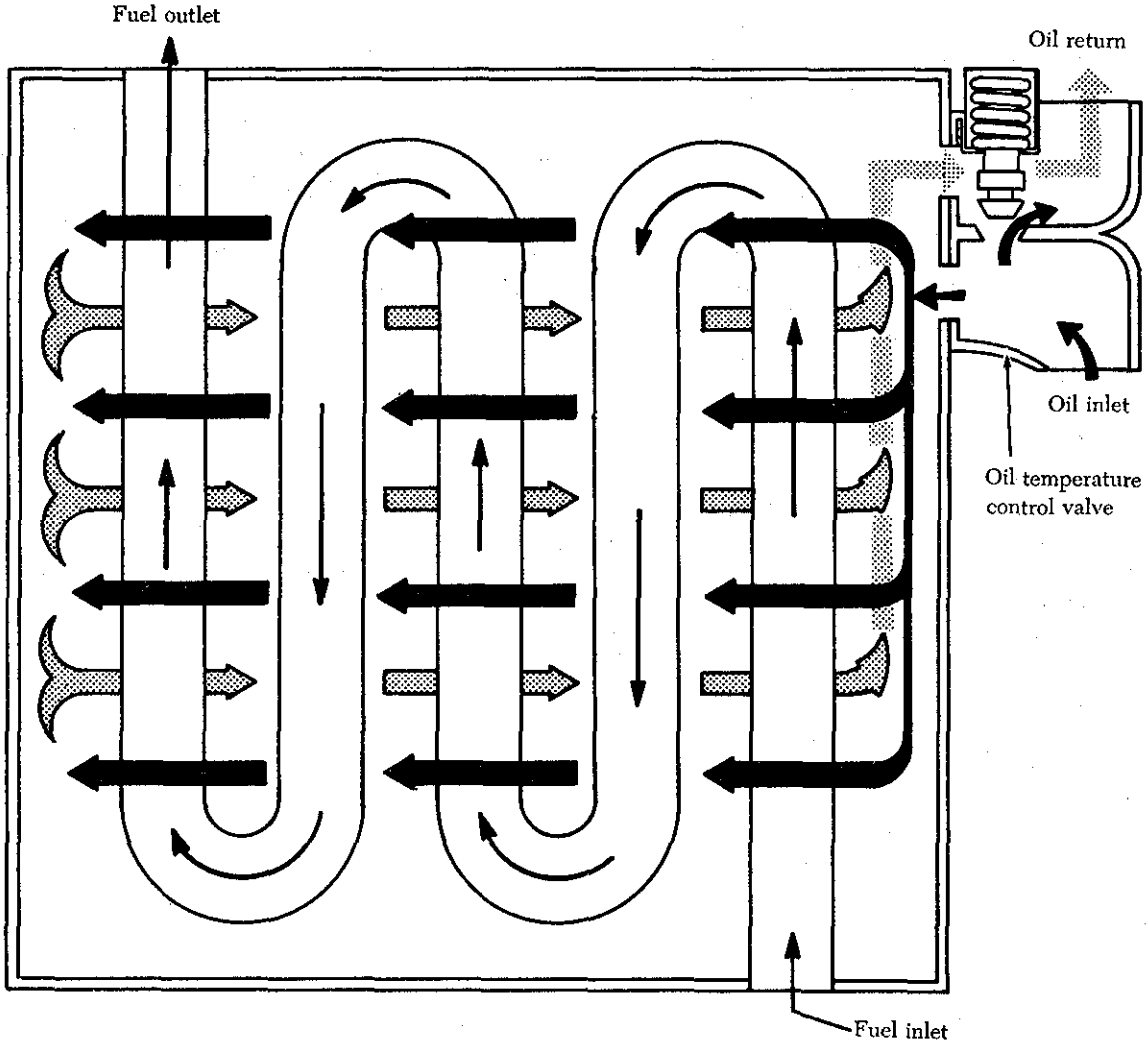


FIGURE 6–29. Fuel/oil heat exchanger cooler.

and discharges pressurized oil to an oil filter located on the housing.

From the oil filter, which is equipped with a bypass valve for operation in case the filter clogs, the pressurized oil is transmitted to a cored passage running through the bottom of the oil pump and accessory drive housing. Near the rear of the housing, this passage is intersected by two passages, one passage transmits pressurized oil to the engine rear bearings. The other passage carries pressurized oil to an axial passage leading to the compressor front bearing support for lubricating the front compressor front bearing and front accessory drive gears.

Intersecting the axial passage is another passage having a smaller bore, which carries pressure oil to the center of the oil pump and accessory drive housing. It is then transmitted into the compressor intermediate case to lubricate the front compressor rear bearing and the rear compressor front bearing. Also intersecting the upper axial passage are two passages conducting oil to the pressure oil gage and to the pressure relief valve. Pressurized oil distributed to the engine main bearings is sprayed on the bearings through fixed orifice nozzles, thus providing a relatively constant oil flow at all engine operating speeds.

The pressure relief valve is located downstream of the pump. It is adjusted to maintain a proper pressure to the oil metering jets in the engine. The pressure relief valve is easily accessible for adjustment.

Maintenance of gas turbine lubrication systems consists mainly of adjusting, removing, cleaning and replacing various components.

To adjust the oil pressure, first remove the adjust-

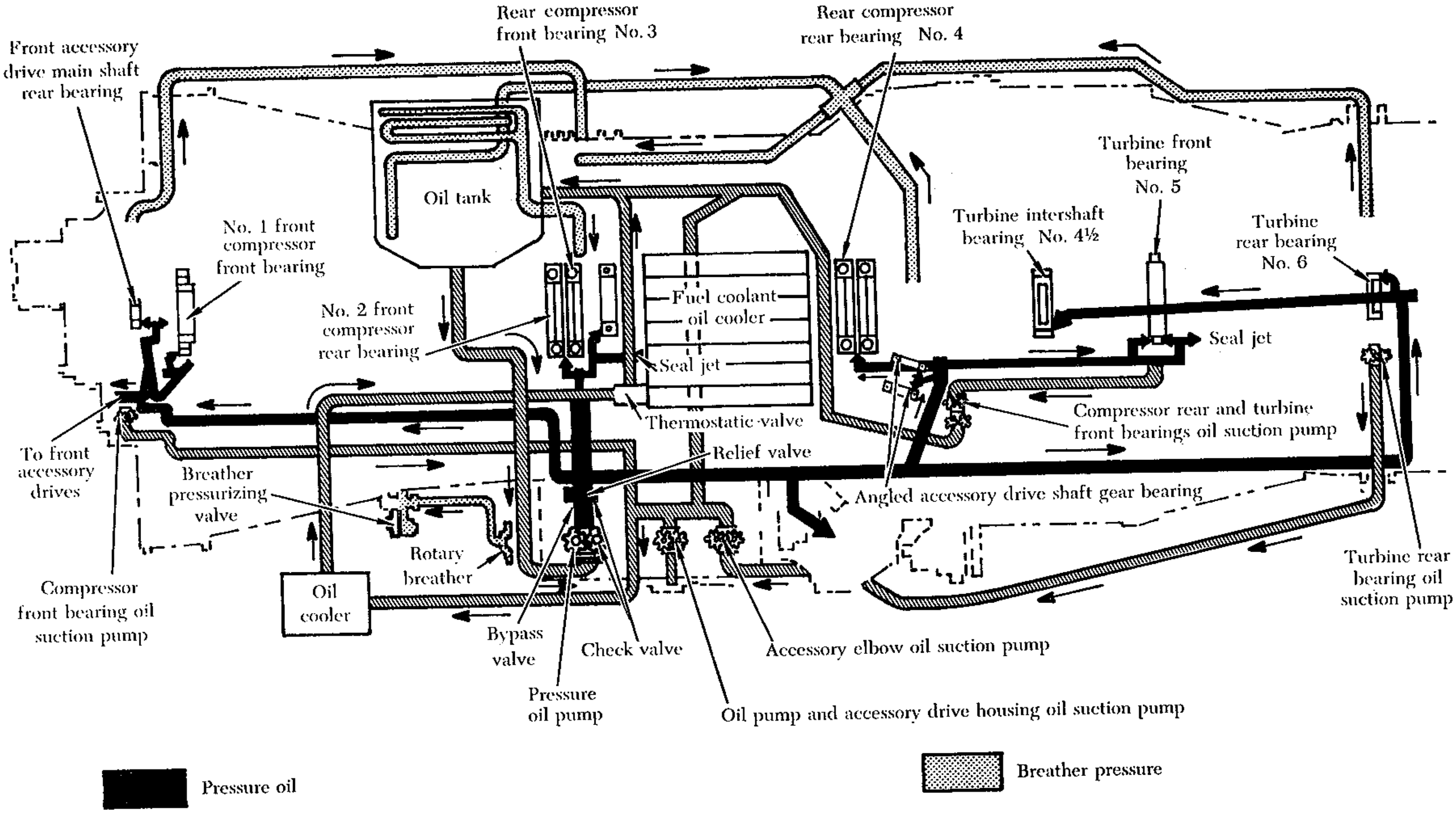


FIGURE 6–30. Typical turbine engine dry-sump lubricating system.

ing screw acorn cap on the oil pressure relief valve. Then loosen the locknut and turn the adjusting screw clockwise to increase, or counterclockwise to decrease, the oil pressure. In a typical turbojet lubrication system, the adjusting screw is adjusted to provide an oil pressure of 45, ±5 p.s.i.g., at approximately 75% of normal rated thrust. The adjustment should be made while the engine is idling; thus, it may be necessary to perform several adjustments before the desired pressure is obtained. When the proper pressure setting is achieved, the adjusting screw locknut is tightened, and the acorn cap is installed with a new gasket, tightened, and secured with lockwire.

Oil Filter Maintenance

The oil filter should be removed at every regular inspection. It should be disassembled, cleaned, and any worn or damaged filter elements replaced. The following steps illustrate typical oil filter removal procedures:

(1) Provide a suitable container for collecting the drained oil.

(2) Remove the filter cover and withdraw the filter assembly (figure 6–31). Discard the old seal.

(3) Install the oil filter assembly in a holding fixture and remove the plug from the filter cover. The filter must be installed in a proper fixture before removing the cover plug to prevent the stacked screens and spacers from flying off under their spring tension.

(4) Carefully remove the filter cover from the fixture; then slide the screens and spacers onto a suitable cleaning rod, keeping them in their proper order. The parts should not be able to slide off the rod during the cleaning operation.

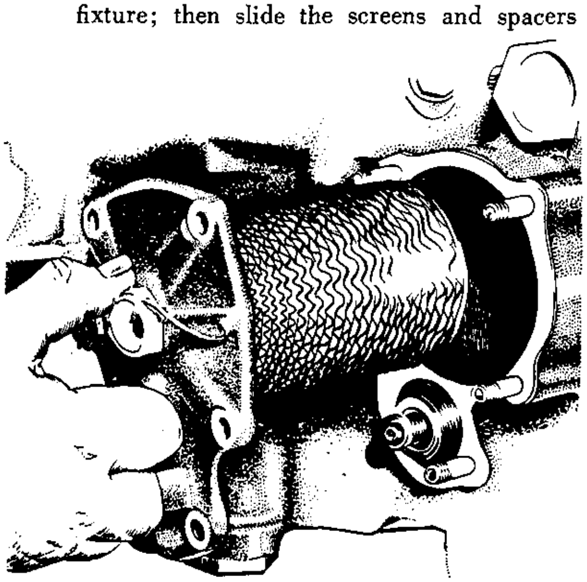


FIGURE 6–31. Removing the oil filter assembly.

(5) Separate the screens and spacers by sliding the parts along the rod. Examine the screens and spacers for foreign matter that would indicate an unsatisfactory condition in the engine.

(6) Immerse the screens and spacers in an approved carbon remover at room temperature for a few minutes. Rinse them in a degreaser fluid or cleaning solvent. Then blow them dry with an air jet.

(7) Assemble the filter spacers and screens on the baffle, using the holding fixture. Make certain that an outlet spacer will be at both ends. Also, make sure each screen is located between an outlet spacer and an inlet spacer. Install the outer end plate on the screen and spacer buildup; then install the cover on the end plate. Place a new seal on the cover plug and install the plug in the threaded end of the baffle. The plug must be tightened to the torque prescribed in the manufacturer's instructions so that the spacers and screens cannot be rotated by hand.

(8) Secure the cover plug with lockwire. Then remove the filter assembly from the holding fixture.

Scavenge System

The scavenge system scavenges the main bearing compartments and, under certain temperature conditions, circulates the scavenged oil through the oil cooler(s) and back to the tank. The scavenge oil system, illustrated in figure 6–30, includes six gear-type pumps. The compressor front bearing oil scavenge pump is driven by the front accessory drive coupling through an intermediate drive gear. It scavenges accumulated oil from the front accessory case. It directs the oil through an external line to a central collecting point in the main accessory case.

The accessory drive housing oil suction pump is driven by an intermediate drive gear. It scavenges oil accumulated from pump leakage and from the No. 2 oil compartment. The oil return from No. 2 and 3 bearings is through internal passages to a central collecting point in the main accessory case.

The accessory elbow oil suction pump, located in the main accessory case, scavenges oil from the angled accessory drive gear housing (accessory elbow housing) and returns it to the central collecting point in the main accessory case. Oil accumulates in the accessory elbow housing by gravity flow from its bushings and bearings and scavenged oil from No. 6 bearing.

The compressor rear bearing oil suction pump is located in the compartment formed by the diffuser inner duct weldment and the No. 5 bearing support, known as the No. 3 oil compartment. The pump is driven by the accessory drive shaft gear. It is secured to the inner duct weldment by an adapter. It scavenges oil from No. 4 and 4-1/2 bearings when the engine is in a level position. When the engine is in a nosedown position, the oil from No. 5 bearing will flow forward to be scavenged by the compressor rear bearing oil suction pump. This pump also directs the scavenged oil to a central collecting point in the main accessory case.

The turbine front bearing oil suction pump is located in the same housing and compartment as the compressor rear bearing oil suction pump. It is driven by the accessory drive shaft gear. It scavenges the oil from No. 5 bearing when the engine is in a level position. When the engine is in a noseup position, the oil from No. 4 and 4-1/2 bearings will flow aft to be scavenged by the turbine front bearing oil suction pump. The turbine front bearing oil suction pump also directs the scavenged oil to the central collecting point in the main accessory case.

The turbine rear bearing oil suction pump is located on the rear inner face of the turbine rear bearing sump, which is the No. 4 oil compartment. It is attached to the turbine rear bearing sump and is driven by a pinion gear. This pump scavenges the oil from the No. 6 bearing compartment and directs the scavenged oil through a passage in the turbine case strut. From there it is directed to the accessory housing where the accessory elbow oil suction pump returns it to the central collecting point in the main accessory case.

There are two controls in the scavenge system to help route the oil for proper cooling. The oil temperature regulator valve is located at the entrance to the fuel/oil heat exchanger (cooler). It operates within a range of 165° F. to full-open 185° F. It directs the flow of return oil around the fuel lines in the cooler (until the valve opens, oil will bypass the cooler). The fuel temperature sensing switch is located in the fuel outlet line of the fuel/oil heat exchanger. It operates within a range of 200° F. to 205° F. to actuate the doors in the air-cooled oil cooler, which will allow air to pass through to cool the oil that is flowing through the cooler at all times.

Maintenance at all regular inspections includes the check for oil leaks and security of mounting of scavenging system components.

Breather Pressurizing System

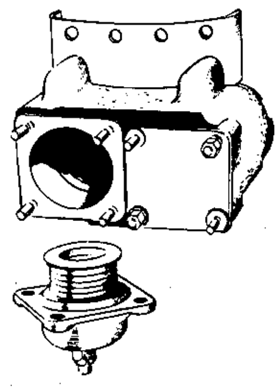
The breather pressurizing system ensures a proper oil spray pattern from the main bearing oil jets and furnishes a pressure head to the scavenge system. Breather tubes in the compressor inlet case, the oil tank, the diffuser case, and the turbine exhaust case are connected to external tubing at the top of the engine. By means of this tubing, the vapor-laden atmospheres of the various bearing compartments and the oil tank are brought together in the compressor intermediate case annulus. The bearing compartment shared by the front compressor rear bearing and the rear compressor front bearing is also vented (through hollow vanes) to the compressor intermediate case annulus. From the annulus the vapors enter the main accessory case, which is mounted at the bottom of the compressor intermediate case.

The breather pressurizing valve (figure 6–32) consists of an aneroid-operated (spring and bellows) valve and a spring-loaded blowoff valve. Pressurization is provided by compressor air which leaks by the seals and enters the oil system.

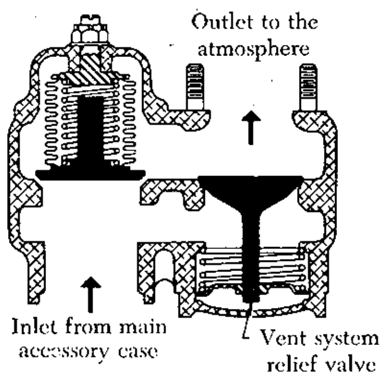
At sea level pressure the breather pressurizing valve is open. It closes gradually with increasing altitude and maintains an oil system pressure sufficient to assure jet oil flows similar to those at sea level. The spring-loaded blowoff valve acts as a pressure relief for the entire breather system. It will open only if pressure above a predetermined maximum value builds up in the system.

A pressure-equalizing valve limits the pressure supplied to the carbon air/oil seal. This aids in preventing overpressurizing in all compartments of the breather system. Air under pressure of up to 54 p.s.i.g. is directed to the pressure equalizing valve. All pressure greater than the 24, ±2 p.s.i.g., preset value of the pressure equalizing valve is spilled into the intermediate case.

The rotary breather (air/oil separator) removes oil from the air by centrifugal action. Its purpose is to reduce the air pressure across the carbon seal. The air from the ninth compressor stage, regardless of the pressure, is directed over the



(A) Breather pressurizing valve



(B) Sectional view of breather pressurizing valve

FIGURE 6–32. Breather pressurizing valve.

forward segment of the carbon seal. The air across the rear carbon seal prevents oil from the No. 2 bearing from entering the airstream. This air is spilled into the intermediate case breather annulus. The air over 25 p.s.i.g. that is directed through the pressure-equalizing valve is also directed to the breather pressurizing valve.

Turbine Engine Wet-Sump Lubrication System

In some engines the lubrication system is of the wet-sump type. There are relatively few engines using a wet-sump type of oil system, because only a few models of centrifugal-flow engines are in operation. A schematic diagram of a wet-sump oil system is shown in figure 6–33.

The components of a wet-sump system are similar to many of those of a dry-sump system. The major difference between the two systems is the location of the oil reservoir.

The reservoir for the wet-sump oil system may be either the accessory gearcase, which consists of the accessory gear casing and the front compressor bearing support casing (figure 6–33), or it may be a sump mounted on the bottom of the accessory case. Regardless of configuration, reservoirs for wet-sump systems are an integral part of the engine and contain the bulk of the engine oil supply.

Included in the wet-sump reservoir shown in figure 6–33 are the following components:

(1) A bayonet-type gage indicates the oil level in the sump.

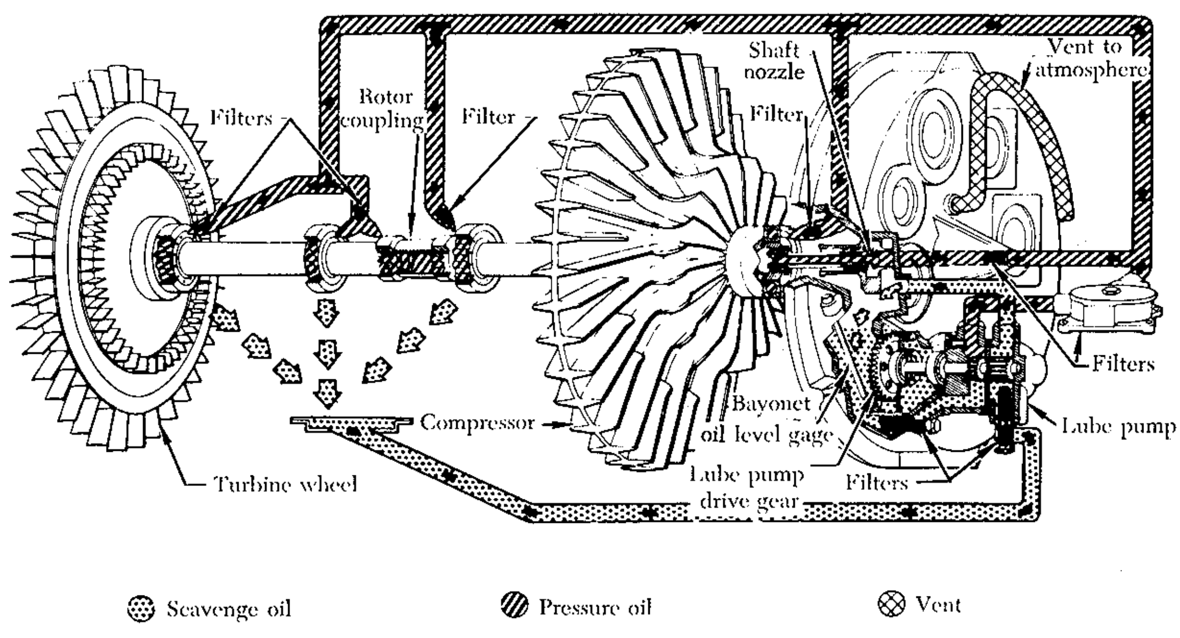


FIGURE 6–33. Turbojet engine wet-sump lubrication system.

(2) Two or more finger strainers (filters) are inserted in the accessory case for straining pressure and scavenged oil just before it leaves or enters the sump. These strainers aid the main oil strainer.

(3) A vent or breather equalizes pressure within the accessory casing.

(4) A magnetic drain plug may be provided to drain the oil and also to trap any ferrous metal particles in the oil. This plug should always be examined closely during inspections. The presence of metal particles may indicate gear or bearing failure.

(5) Provision may also be made for a temperature bulb and an oil pressure fitting.

This system is typical of all engines using a wet-sump lubrication system. The bearing and drive gears in the accessory drive casing are lubricated by a splash system. The oil for the remaining points of lubrication leaves the pump under pressure and passes through a filter to jet nozzles that direct the oil into the rotor bearings and couplings. Most wet-sump pressure systems are variable-pressure systems in which the pump outlet pressure depends on the engine r.p.m.

The scavenged oil is returned to the reservoir (sump) by gravity and by pump suction. Oil from the front compressor bearing and the accessories drive coupling shaft drains directly into the reservoir. Oil from the turbine coupling and the remaining rotor shaft bearings drains into a sump from which the oil is pumped by the scavenge element through a finger screen into the reservoir.

ENGINE COOLING SYSTEMS

Excessive heat is always undesirable in both reciprocating and turbine aircraft engines. If means were not available for its control or elimination, major damage or complete engine failure would occur.

Reciprocating Engine Cooling Systems

An internal-combustion engine is a heat machine that converts chemical energy in the fuel into mechanical energy at the crankshaft. It does not do this without some loss of energy, however, and even the most efficient aircraft engines may waste 60 to 70% of the original energy in the fuel. Unless most of this waste heat is rapidly removed, the cylinders may become hot enough to cause complete engine failure.

Excessive heat is undesirable in any internal-combustion engine for three principal reasons:

(1) It affects the behavior of the combustion of the fuel/air charge.

(2) It weakens and shortens the life of engine parts.

(3) It impairs lubrication. If the temperature inside the engine cylinder is too great, the fuel/air mixture will be preheated, and combustion will occur before the desired time. Since premature combustion causes detonation, knocking, and other undesirable conditions, there must be a way to eliminate heat before it causes damage.

One gallon of aviation gasoline has enough heat value to boil 75 gallons of water; thus, it is easy to see that an engine which burns 4 gallons of fuel per minute releases a tremendous amount of heat. About one-fourth of the heat released is changed into useful power. The remainder of the heat must be dissipated so that it will not be destructive to the engine. In a typical aircraft powerplant, half of the heat goes out with the exhaust, and the other is absorbed by the engine. Circulating oil picks up part of this soaked-in heat and transfers it to the airstream through the oil cooler. The engine cooling system takes care of the rest.

Cooling is a matter of transferring the excess heat from the cylinders to the air, but there is more to such a job than just placing the cylinders in the airstream.

A cylinder on a large engine is roughly the size of a gallon jug. Its outer surface, however, is increased by the use of cooling fins so that it presents a barrel-sized exterior to the cooling air. Such an arrangement increases the heat transfer by radiation. If too much of the cooling fin area is broken off, the cylinder cannot cool properly and a hotspot will develop. Therefore, cylinders are normally replaced when a specified number of square inches of fins are missing.

Cowling and baffles are designed to force air over the cylinder cooling fins (figure 6–34). The baffles

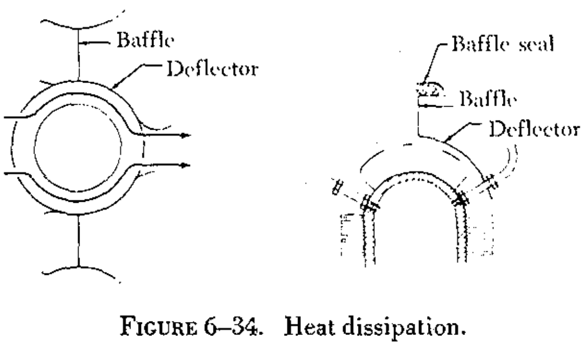


FIGURE 6–34. Heat dissipation.

direct the air close around the cylinders and prevent it from forming hot pools of stagnant air while the main streams rush by unused. Blast tubes are built into the baffles to direct jets of cooling air onto the rear spark plug elbows of each cylinder to prevent overheating of ignition leads.

An engine can have an operating temperature that is too low. For the same reasons that an engine is warmed up before takeoff, it is kept warm during flight. Fuel evaporation and distribution and oil circulation depend on an engine being kept warm. The automobile engine depends on a thermostatic valve in the water system to keep the engine in its most efficient temperature range. The aircraft engine, too, has temperature controls. These controls regulate air circulation over the engine. Unless some controls are provided, the engine will overheat on takeoff and get too cold in high-speed and low-power letdowns.

The most common means of controlling cooling is the use of cowl flaps, as illustrated in figure 6–35.

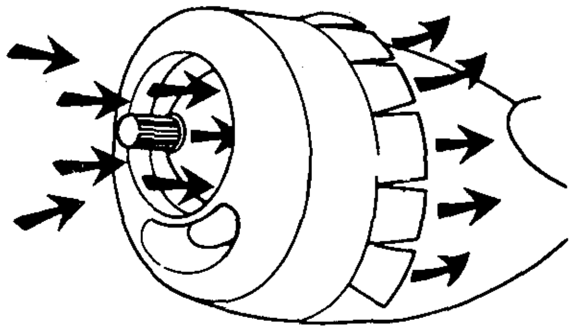


FIGURE 6–35. Regulating the cooling airflow.

These flaps are opened and closed by electric-motor-driven jackscrews, by hydraulic actuators, or manually in some light aircraft. When extended for increased cooling, the cowl flaps produce drag and sacrifice streamlining for the added cooling. On takeoff, the cowl flaps are opened only enough to keep the engine below the red-line temperature. Heating above the normal range is allowed so that drag will be as low as possible. During ground operations, the cowl flaps should be opened wide since drag does not matter.

Some aircraft use augmentors (figure 6–36) to provide additional cooling airflow. Each nacelle has two pairs of tubes running from the engine compartment to the rear of the nacelle. The exhaust collectors feed exhaust gas into the inner augmentor tubes. The exhaust gas mixes with air that has passed over the engine and heats it to form a high-temperature, low-pressure, jetlike exhaust. This low-pressure area in the augmentors draws additional cooling air over the engine. Air entering the outer shells of the augmentors is heated through contact with the augmentor tubes but is not contaminated with exhaust gases. The heated air from the shell goes to the cabin heating, defrosting, and anti-icing system.

Augmentors use exhaust gas velocity to cause an airflow over the engine so that cooling is not entirely dependent on the prop wash. Vanes installed in the augmentors control the volume of air. These vanes usually are left in the trail position to permit maximum flow. They can be closed to increase the heat for cabin or anti-icing use or to prevent the

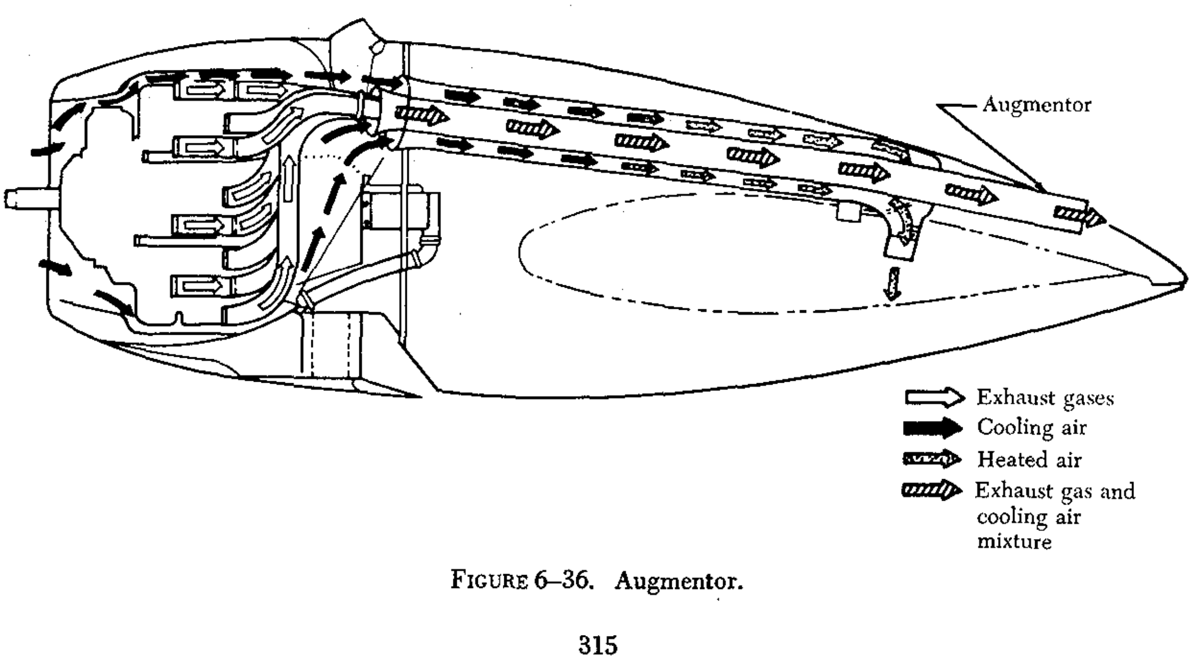


FIGURE 6–36. Augmentor.

engine from cooling too much during descent from altitude. In addition to augmentors, some aircraft have residual heat doors or nacelle flaps that are used mainly to let the retained heat escape after engine shutdown. The nacelle flaps can be opened for more cooling than that provided by the augmentors.

A modified form of the previously described augmentor cooling system is used on some light aircraft. Figure 6–37 is an outline diagram of such a system.

As shown in figure 6–37, the engine is pressure-cooled by air taken in through two openings in the nose cowling, one on each side of the propeller spinner. A pressure chamber is sealed off on the top side of the engine with baffles properly directing the flow of cooling air to all parts of the engine compartment. Warm air is drawn from the lower part of the engine compartment by the pumping action of the exhaust gases through the exhaust ejectors. This type of cooling system eliminates the use of controllable cowl flaps and assures adequate engine cooling at all operating speeds.

Many light aircraft use only one or two engine cowl flaps to control engine temperature. As shown in figure 6–38, two cowl flaps, operated by a single control in the cabin, are located at the lower aft end of the engine nacelle. Cutouts in the flaps permit extension of engine exhaust stacks through the nacelle. The flaps are operated by a manual control in the cockpit to control the flow of air directed by baffles around the cylinders and other engine components.

Some small aircraft that have horizontally opposed engines use this type of cowling. The cowl flaps are controlled by an electrically operated gill-type flap on the trailing edge of each cowling.

Reciprocating Engine Cooling System Maintenance

The engine cooling system of most reciprocating engines usually consists of the engine cowling, cylinder baffles, cylinder fins, and some type of cowl flaps. In addition to these major units, there is also some type of temperature-indicating system (cylinder head temperature).

The cowling performs two functions: (1) It streamlines the bulky engine to reduce drag, and

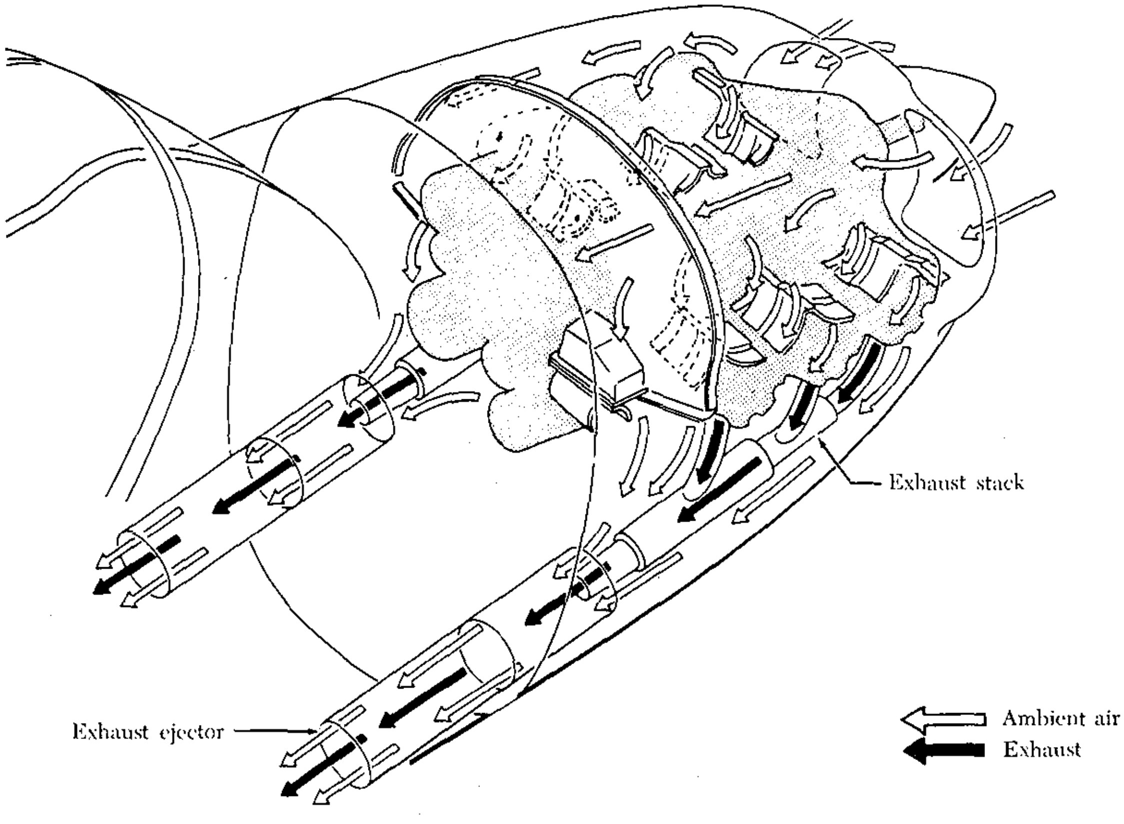
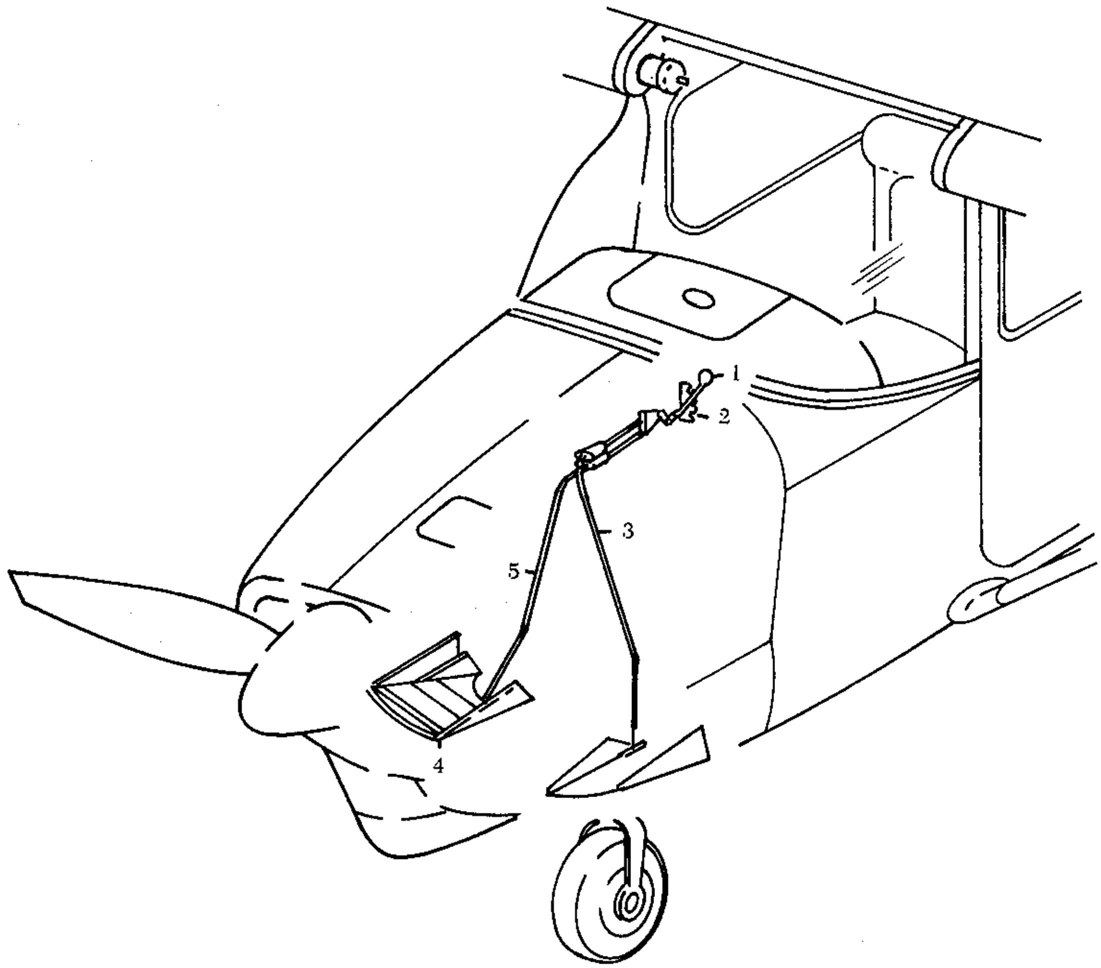


FIGURE 6–37. Engine cooling and exhaust system.



1. Cowl flap control lever
2. Position bracket
3. L. H. cowl flap control
4. Cowl flaps
5. R. H. cowl flap control

FIGURE 6–38. Small aircraft cowl flaps.

(2) it forms an envelope around the engine which forces air to pass around and between the cylinders, absorbing the heat dissipated by the cylinder fins.

The cylinder baffles are metal shields, designed and arranged to direct the flow of air evenly around all cylinders. This even distribution of air aids in preventing one or more cylinders from being excessively hotter than the rest.

The cylinder fins radiate heat from the cylinder walls and heads. As the air passes over the fins, it absorbs this heat, carries it away from the cylinder, and is exhausted overboard through the cowl flaps.

The controllable cowl flaps provide a means of decreasing or increasing the exit area at the rear of the engine cowling. Closing the cowl flaps decreases the exit area, which effectively decreases the amount of air that can circulate over the cylinder fins. The decreased airflow cannot carry away as much heat; therefore, there is a tendency for the engine temperature to increase. Opening the cowl flaps makes the exit area larger. The flow of cooling air over the cylinders increases, absorbing more heat, and the tendency is then for the engine temperature to decrease. Good inspection and maintenance in the care of the engine cooling system will aid in overall efficient and economical engine operation.

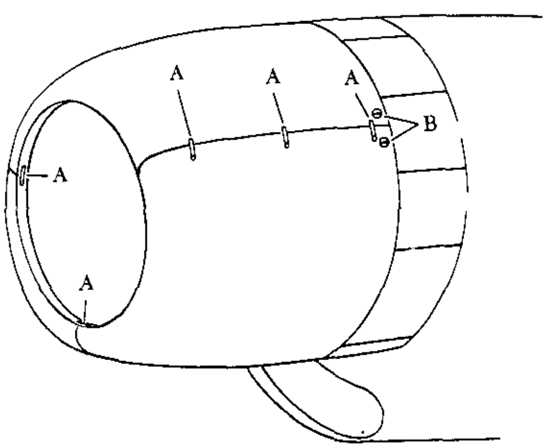
Maintenance of Engine Cowling

Of the total ram airflow approaching the airborne engine nacelle, only about 15 to 30% enters the cowling to provide engine cooling. The remaining air flows over the outside of the cowling. Therefore, the external shape of the cowl must be faired in a manner that will permit the air to flow smoothly over the cowl with a minimum loss of energy.

The engine cowling discussed in this section is typical of that used on many radial or horizontally opposed engines. All cooling systems function in the same manner, with minor engineering changes designed for specific installations.

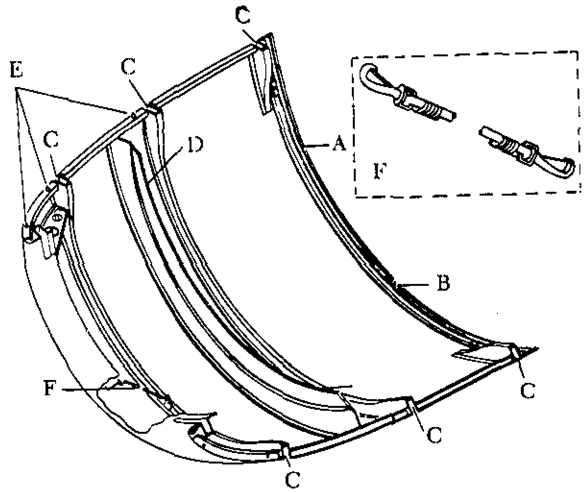
The ring cowl is manufactured in removable sections, the number of which varies with the aircraft make and model. The installation shown in figure 6–39 contains three sections that are locked together, when installed, by the toggle latches (item A). In addition to this toggle latching system, safety locks (item B) are installed on each section of the ring cowl. These safety locks prevent the cowling from coming apart if the toggle latch does not hold for any reason.

The ring cowl panels, made from sheet aluminum, have a smooth external surface to permit undisturbed airflow over the cowl. The internal construction is designed to give strength to the panel and, in addition, to provide receptacles for the toggle latches, cowl support ring track, and engine air seal. Figure 6–40 shows the internal construction of a ring cowl panel. A cowl support ring track riveted to the panel fits over the cowl support ring to position the cowling fore and aft. A locating pin in the center of the track fits through a hole in the cowl support ring. This establishes the correct position for installing each panel around the cowl support ring. Ribs run across the cowl panel between the toggle latch mechanism receptacles on each side of the panel to strengthen the panel.



A. Toggle latches B. Safety locks

FIGURE 6–39. Ring cowl panel assembly.



A. Cowl support ring track
B. Locator pin
C. Toggle latch mechanism receptacle
D. Engine air seal
E. Ring cowl positioning pin
F. Bungee support cord

FIGURE 6–40. Ring cowl panel construction.

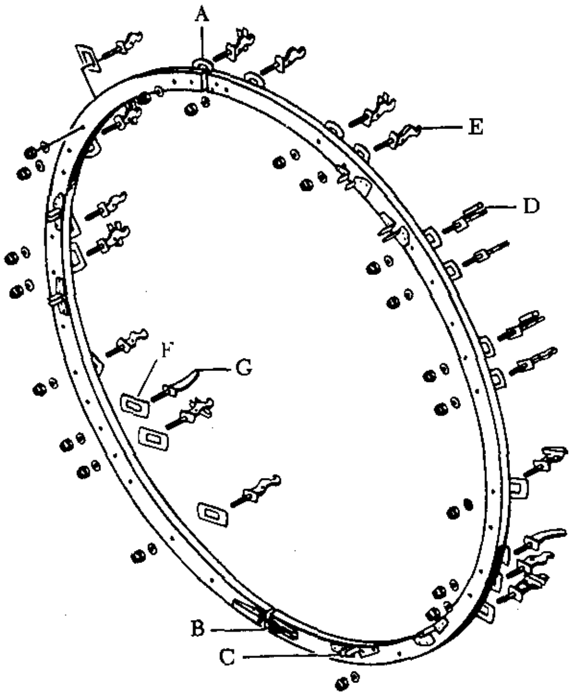
An air seal (figure 6–40), constructed of rubber material, is bolted to a metal rib riveted to the cowl panel. This seal, as the name implies, seals the air in the engine section, preventing the air from escaping along the inner surface of the panel without circulating around the cylinders. The engine air seal must be used on engines that have a complete cylinder baffling system that covers the cylinder heads. Its purpose is to force the air to circulate around and through the baffle system. The air seal is not used on aircraft engines that have only the intercylinder baffles and do not enclose the cylinder heads.

The cowl support ring is attached rigidly to the engine mounting ring to provide a sturdy support for the cowl panels and also for the attachment of the cowl flaps. The support ring usually comes in two pieces connected together to form the ring. Figure 6–41 illustrates a typical support ring.

INSPECTION OF COWLING

The support ring and cowl panels are inspected during each regular engine and aircraft inspection. Removing the cowling for maintenance provides an opportunity for more frequent inspection of the cowling.

The cowling panels are inspected for scratches, dents, and tears in the panels. This type of damage causes weakness of the panel structure, increases



A. Top ring half flexible connection
B. Adjustable ring half connection
C. Locking angles
D. Cowl flap hinge terminal (bonding clip)
E. Cowl flap hinge terminal
F. Cowl flap hinge locking plate
G. Cowl flap hinge track

FIGURE 6–41. Cowl support ring.

drag by disrupting airflow, and contributes to the starting of corrosion.

The cowling panel latches should be inspected for pulled rivets and loose or damaged handles. The safety locks should be checked for damaged rivets and the condition of the compression spring. The hole through which the safety lock passes should be checked to determine that it is not worn or cracked. These conditions, if serious, necessitate replacing or repairing the panel.

The internal construction of the panel should be examined to see that the reinforcing ribs are not cracked and that the air seal is not damaged.

The support ring should be inspected for security of mounting and cracks. The cowl flap hinges and cowl flap hinge bondings should be checked for security of mounting and for breaks or cracks. These inspections are visual checks and should be performed frequently to ensure that the cowling is serviceable and is contributing to efficient engine cooling.

ENGINE CYLINDER COOLING FIN INSPECTION

The cooling fins are of the utmost importance to the cooling system, since they provide a means of transferring the cylinder heat to the air. Their condition can mean the difference between adequate or inadequate cylinder cooling. The fins are inspected at each regular inspection.

Fin area is the total area (both sides of the fin) exposed to the air. During the inspection, the fins should be examined for cracks and breaks (figure 6–42). Small cracks are not a reason for cylinder removal. These cracks can be filed or even sometimes stop-drilled to prevent any further cracking. Rough or sharp corners on fins can be smoothed out by filing, and this action will eliminate a possible source of new cracks. However, before re-profiling cylinder cooling fins, consult the manufacturer's service or overhaul manual for the allowable limits.

The definition of fin area becomes important in the examination of fins for broken areas. It is a determining factor for cylinder acceptance or removal. For example, on a certain engine, if more than 12 in. in length of any one fin, as measured at its base, is completely broken off, or if the total fins broken on any one cylinder head exceed 83 sq. in. of area, the cylinder is removed and replaced. The reason for removal in this case is that an area of that size would cause a hot spot on the cylinder, since very little heat transfer could occur.

Where adjacent fins are broken in the same area the total length of breakage permissible is 6 in. on any two adjacent fins, 4 in. on any three adjacent fins, 2 in. on any four adjacent fins, and 1 in. on any five adjacent fins. If the breakage length in adjacent fins exceeds this prescribed amount, the

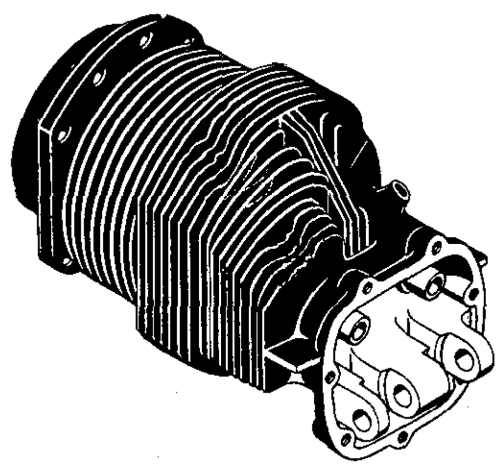


FIGURE 6–42. Cracked cylinder fins.

cylinder should be removed and replaced. These breakage specifications are applicable only to the engine used in this discussion as a typical example. In each specific case, applicable manufacturer's instructions should be consulted.

Cylinder Baffle and Deflector System Inspection

Reciprocating engines use some type of intercylinder and cylinder head baffles to force the cooling air into close contact with all parts of the cylinders. Figure 6–43 shows a baffle and deflector system around a cylinder. The air baffle blocks the flow of air and forces it to circulate between the cylinder and the deflectors.

Figure 6–44 illustrates a baffle and deflector arrangement designed to cool the cylinder head. The air baffle prevents the air from passing away from the cylinder head and forces it to go between the head and deflector.

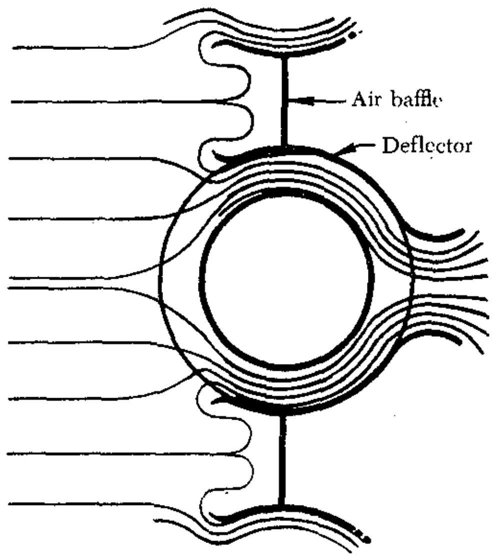


FIGURE 6–43. Cylinder baffle and deflector system.

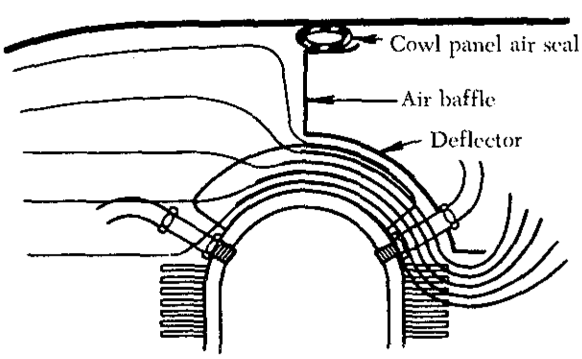


FIGURE 6–44. Cylinder head baffle and deflector system.

Although the resistance offered by baffles to the passage of the cooling air demands that an appreciable pressure differential be maintained across the engine to obtain the necessary airflow, the volume of cooling air required is greatly reduced by employing properly designed and located cylinder deflectors. As shown in figure 6–45, the airflow approaches the nacelle and piles up at the face of the engine, creating a high pressure in front of the cylinders. This piling up of the air reduces the air velocity. The cowl flaps, of course, produce the low-pressure area. As the air nears the cowl flap exit, it is speeded up again and merges smoothly with the airstream. The pressure differential between the front and the rear of the engine forces the air past the cylinders through the passages formed by the deflectors.

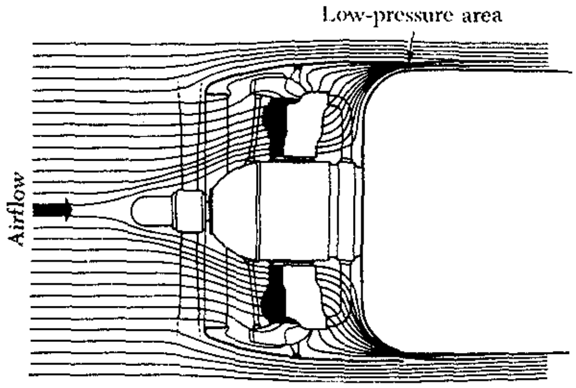


FIGURE 6–45. Engine airflow.

The baffles and deflectors normally are inspected during the regular engine inspection, but they should be checked whenever the cowling is removed for any purpose. Checks should be made for cracks, dents, or loose holddown studs. Cracks or dents, if severe enough, would necessitate repair or removal and replacement of these units. However, a crack that has just started can be stop-drilled, and dents can be straightened, permitting further service from these baffles and deflectors.

Cowl Flap Installation and Adjustment

During cowl flap installation, adjustments are made to assure the correct "open and close" tolerances of the cowl flaps. This tolerance is of the utmost importance. If the cowl flap is permitted to open too far, the air exiting from the engine section is increased in velocity, thus permitting too great a cooling of the cylinders. Also, if the cowl flaps are not adjusted to open the desired amount, the cylinder head temperature will be higher than allowable limits under certain operating conditions. For each engine installation the cowl flaps are set for tolerances that will permit them to open and close a correct amount, keeping the cylinder head temperature within allowable limits.

It is important to install the cowl flaps correctly, adjust the jackscrews, adjust the "open and close" limit switches, and inspect the system.

The installation used in this example of a typical large reciprocating engine has nine cowl flaps. The flaps are numbered clockwise (looking from the rear toward the front of the engine), starting with the No. 1 flap and continuing through the No. 9 flap. The Nos. 1 and 9 flaps (figure 6–46) are stationary and 2 through 8 are movable flaps. The flaps are hinged near their forward end to the cowl support ring and connected near the aft end of the cowl flap jackscrews.

There are seven cowl flap jackscrews interconnected by a flexible drive shaft. This type of connection permits all movable cowl flaps to move simultaneously and evenly when the cowl flap actuating motor is energized. The stationary flaps (1 and 9) are fastened by turnbuckles, one for the No. 1 flap, and two for No. 9 flap.

The following checks and inspections are typical of those made to maintain an efficient cowl flap system:

(1) Check the cowl flaps for response by actuating the cockpit control from the "open" to the "closed," and back to the "open" position. The flaps should respond rapidly and smoothly. If a cowl flap indicator is installed, observe the indications received for synchronization with the flaps in the "open" and "closed" positions.

(2) With the cowl flaps open, check for cracks, distortion, or security of mounting. Grasp the flap at the trailing edge, shake laterally and up and down to determine the condition of the bushings, bearings, or the turnbuckles. Looseness of the flaps during this check indicates worn bushings or bearings that should be replaced. Inspect the hinges and hinge terminals for wear, breaks, or cracks; check the hinges for security of mounting on the cowl support ring.

(3) Measure the "open" and "closed" positions of the cowl flaps to check for specified tolerances and adjust as necessary.

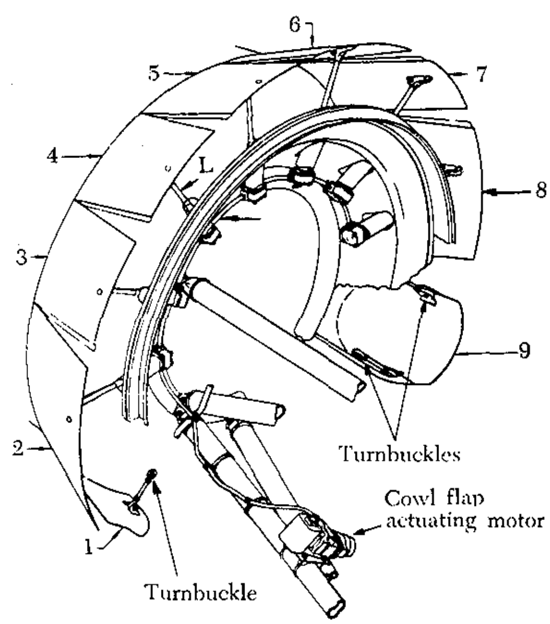


FIGURE 6–46. Cowl flap installation.

Cylinder Temperature Indicating System

This system usually consists of an indicator, electrical wiring, and a thermocouple. The wiring is between the instrument and the nacelle firewall. At the firewall, one end of the thermocouple leads connect to the electrical wiring, and the other end of the thermocouple leads connect to the cylinder.

The thermocouple consists of two dissimilar metals, generally constantan and iron, connected by wiring to an indicating system. If the temperature of the junction is different from the temperature where the dissimilar metals are connected to wires, a voltage is produced. This voltage sends a current through wires to the indicator, a current-measuring instrument graduated in degrees.

The thermocouple end that connects to the cylinder is either the bayonet or gasket type. To install the bayonet type, the knurled nut is pushed down and turned clockwise until it is snug. In removing this type, the nut is pushed down and turned counterclockwise until released. The gasket type fits under the spark plug and replaces the normal spark plug gasket.

When installing a thermocouple lead, remember not to cut off the lead because it is too long, but coil and tie up the excess length. The thermocouple is designed to produce a given amount of resistance. If the length of the lead is reduced, an incorrect temperature reading will result. The bayonet or gasket of the thermocouple is inserted or installed on the hottest cylinder of the engine, as determined in the block test.

When the thermocouple is installed and the wiring connected to the instrument, the indicated reading is the cylinder temperature. Prior to operating the engine, provided it is at ambient temperature, the cylinder head temperature indicator will indicate the free outside air temperature; that is one test for determining that the instrument is working correctly.

The cover glass of the cylinder head temperature indicator should be checked regularly to see that it has not slipped or that it is not cracked. The cover glass should be checked for indications of missing or damaged decals that indicate temperature limitations. If the thermocouple leads were excessive in length and had to be coiled and tied down, the tie should be inspected for security or chafing of the wire. The bayonet or gasket should be inspected for cleanness and security of mounting. When operating the engine, if the cylinder head temperature pointer fluctuates, all the electrical connections should be checked.

TURBINE ENGINE COOLING

The intense heat generated when fuel and air are burned necessitates that some means of cooling be provided for all internal combustion engines. Reciprocating engines are cooled either by passing air over fins attached to the cylinders or by passing a liquid coolant through jackets that surround the cylinders. The cooling problem is made easier because combustion occurs only during every fourth stroke of a four-stroke-cycle engine.

The burning process in a gas turbine engine is continuous, and nearly all of the cooling air must be passed through the inside of the engine. If only enough air were admitted to the engine to provide an ideal air/fuel ratio of 15:1, internal temperatures would increase to more than 4,000° F. In practice, a large amount of air in excess of the ideal ratio is admitted to the engine. The large surplus of air cools the hot sections of the engine to acceptable temperatures ranging from 1,100° to 1,500° F.

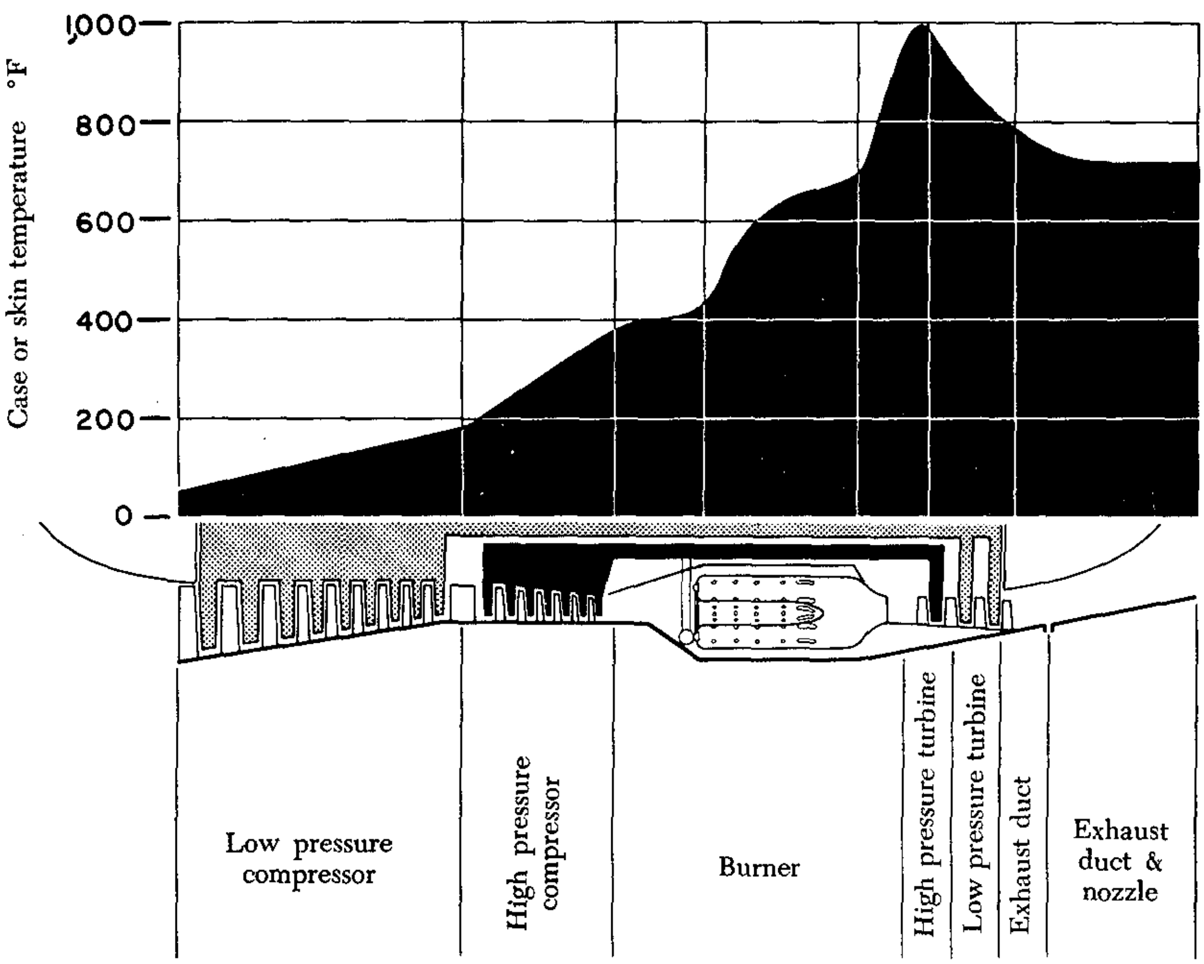


FIGURE 6–47. Typical outer-case temperatures for dual axial-compressor turbojet engine.

Figure 6–47 illustrates the approximate engine outer-case (skin) temperatures encountered in a properly cooled dual axial-compressor turbojet engine. Because of the effect of cooling, the temperatures of the outside of the case are considerably less than those encountered within the engine. The hottest spot occurs opposite the entrance to the first stage of the turbine. Although the gases have begun to cool a little at this point, the conductivity of the metal in the case carries the heat directly to the outside skin.

The air passing through the engine cools the combustion-chamber burner cans or liners. The cans are constructed to induce a thin, fast-moving film of air over both the inner and outer surfaces of the can or liner. Can-annular-type burners frequently are provided with a center tube to lead cooling air into the center of the burner to promote high combustion-efficiency and rapid dilution of the hot combustion gases while minimizing pressure losses. In all types of gas turbines, large amounts of relatively cool air join and mix with the burned gases aft of the burners to cool the hot gases just before they enter the turbines.

Cooling-air inlets frequently are provided around the exterior of the engine to permit the entrance of air to cool the turbine case, the bearings, and the turbine nozzle. In some instances, internal air is bled from the engine compressor section and is vented to the bearings and other parts of the engine. Air vented into or from the engine is ejected into the exhaust stream. When an accessory case is mounted at the front of the engine, it is cooled by inlet air. When located on the side of the engine, the case is cooled by outside air flowing around it.

The engine exterior and the engine nacelle are cooled by passing air between the case and the shell of the nacelle (figure 6–48). The engine compartment frequently is divided into two sections. The forward section is built around the engine-air-inlet duct; the aft section is built around the engine. A fume-proof seal is provided between the two sections. The advantage of such an arrangement is that fumes from possible leaks in the fuel and oil lines contained in the forward section cannot become ignited by contact with the hot sections of the engine. In flight, ram air provides ample cooling of the two compartments. On the ground, air circulation is provided by the effect of reduced pressure at the rear of the engine compartment, produced by gases flowing from the exhaust nozzle.

Turbine Engine Insulation Blankets

To reduce the temperature of the structure in the vicinity of the exhaust duct or afterburner and to eliminate the possibility of fuel or oil coming in contact with the hot parts of the engine, it is sometimes necessary to provide insulation on the exhaust duct of gas turbine engines. As shown in figure 6–49, the exhaust-duct surface temperature runs quite high.

A typical insulation blanket and the temperatures obtained at various locations are shown in figure 6–49. This blanket contains fiber glass as the low-conductance material and aluminum foil as the radiation shield. The blanket is suitably covered so that it does not become oil-soaked. Insulation blankets have been used rather extensively on some

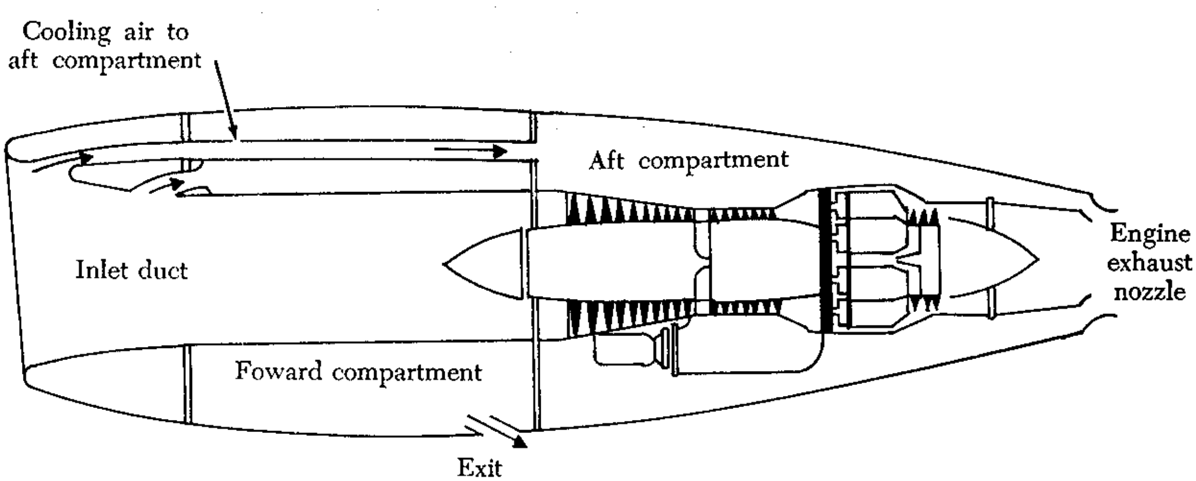


FIGURE 6–48. Typical engine nacelle cooling arrangement.

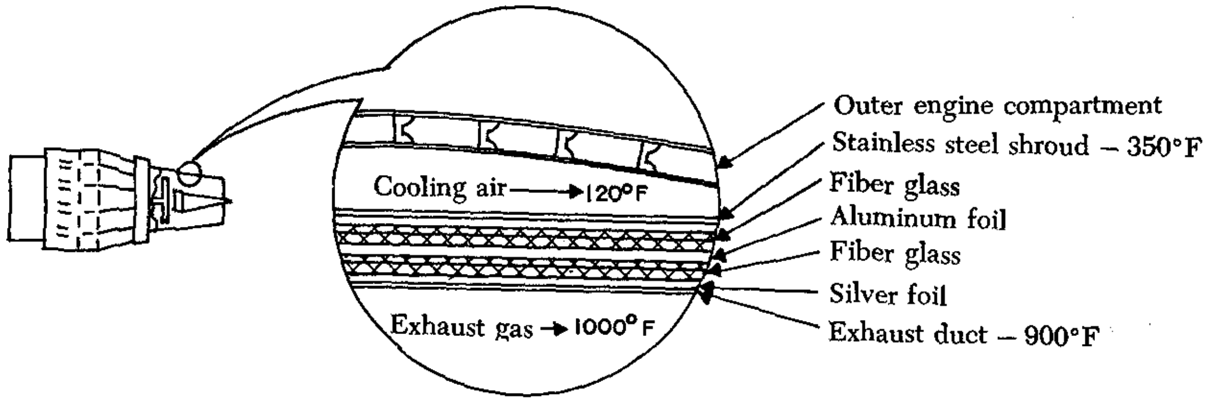


FIGURE 6–49. Typical engine insulation blanket.

centrifugal-flow engine installations, but are not commonly employed for axial-flow compressor engines if the installation permits the more desirable air-cooling method.